Appendix A

Vital Signs and Conceptual Diagrams for the Eastern Rivers and Mountains Network

Summary

This appendix contains the most current list of vital signs, associated narratives, potential measure, etc. for the Eastern Rivers and Mountains Network. Throughout the body of the Phase II Report and other associated appendices there are many references to master lists, short lists, working lists, and candidate lists of vital signs. There are also various iterations of the vital sign narratives. The information contained herein should be considered the most current list of, and information concerning, the network vital signs.

The Eastern Rivers and Mountains Network has identified 37 vital signs that represent a systems approach to our monitoring program. Three vital signs relate to air and climate, three relate to geology and soils, five relate to water, two relate to human use, four relate to ecosystem pattern and processes, and 20 relate to biological integrity. The network developed this list through a process of meetings and ranking exercises to produce a "short-list" of vital signs we plan to implement or develop in the next three to five years.

The term vital sign is defined in this program as "a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values" (http://science.nature.nps.gov/im/monitor/).

Contents

The list of the current 37 network vital signs, the general monitoring objective and potential measures for each is presented in **Table A-1**. We then present conceptual diagrams that show, pictorially, how the vital signs integrate with the network ecosystems and management issues. Each of these "**conceptual diagrams**" has a caption explaining the main elements of the diagrams and references the reader to specific **summary narratives of each network vital sign** (the final sections of this document). These summary narratives are meant to give the reader much more detailed information about a particular vital sign.

EASTERN RIVERS AND MOUNTAINS NETWORK

Ecological Monitoring Framework

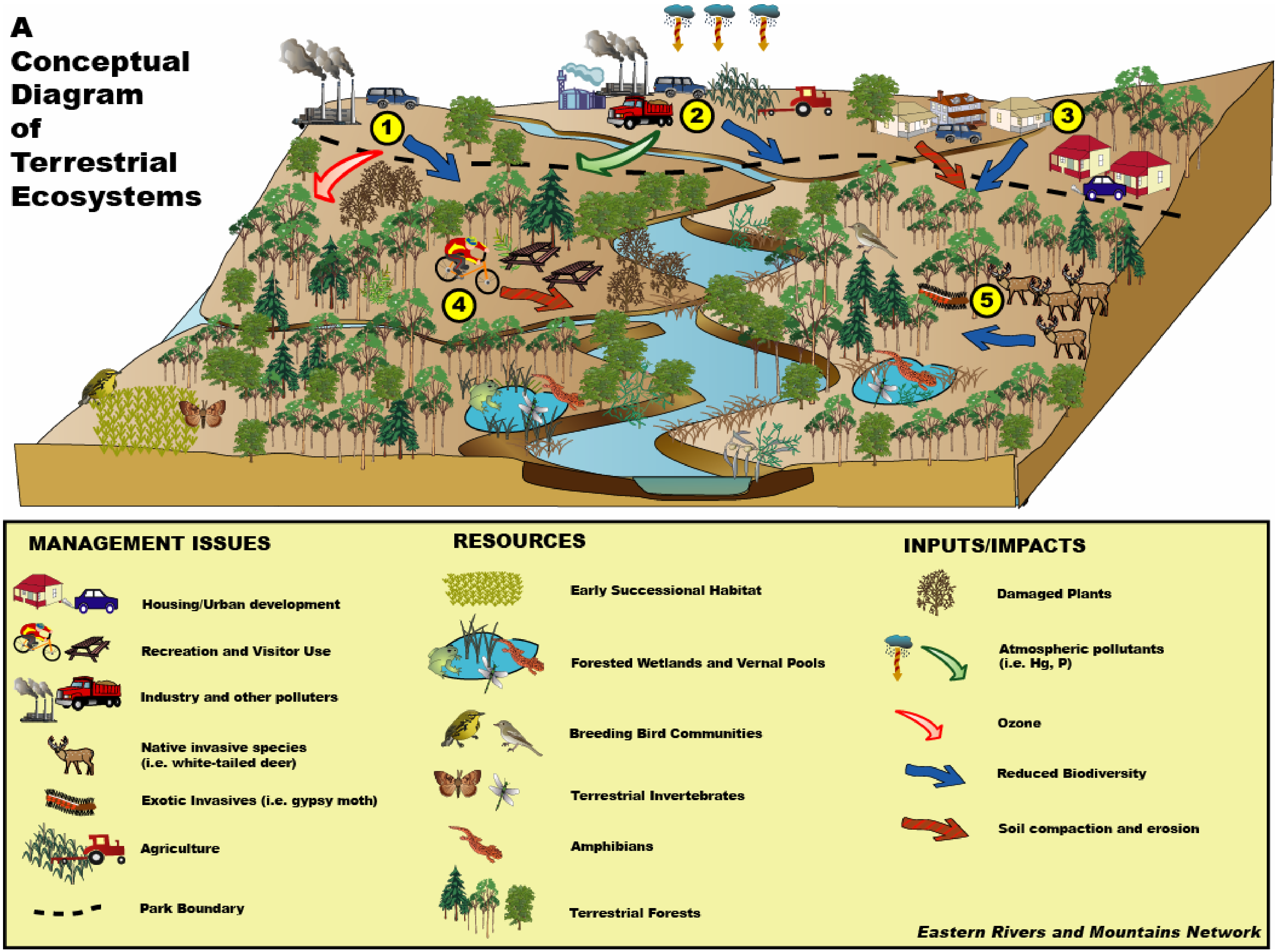
The NPS Ecological Monitoring Framework is a systems-based, heirarchical, organizational tool for promoting communication, collaboration, and coordination among parks, networks, programs, and agencies involved in ecological monitoring. Vital signs selected by parks and networks for monitoring are assigned to the Level 3 category that most closely pertains to that vital sign. For example, the vital sign "Shoreline Change" is assigned to the Level 3 category of "Coastal/oceanographic features and processes" within the Level 2 category of Geomorphology and Level 1 category of "Geology and Soils". The Level 1 categories will be used in a "Natural Resource Scorecard" to report on the condition of park resources. To promote collaboration among networks, a database has been developed using the framework to show which parks and networks will implement monitoring of vital signs within each Level 1, 2, and 3 category.

Level 1 Category	Level 2 Category	Level 3 Category - "Vital Sign"	VS Number	General Monitoring Objective (specific monitoring and sampling objectives to be developed for each Vital Sign)	Potential Measures
Air and Climate	Air Quality	Ozone	1	Document status and monitor trends in ozone concentration surrounding the ERMN and/or ozone injury occurring in sensitive plant species in the ERMN.	Regional atmospheric ozone concentration, foliar ozone damage to sensitive plants
		Wet and Dry Deposition	2	Document status and monitor trends in atmospheric pollutant emissions present in the ERMN and/or deposition injury to sensitive species in the ERMN.	Wet deposition chemistry (pH, NO3-, SO4=), continuous sulfur (SO2) dioxide concentrations; Hg, Pb, Cd, Co, Zn, N. NADP/NTN; CASTNet
	Weather & Climate	Weather & Climate	4	Monitor key measurable climate parameters to determine rate and extent of climate trends in the ERMN.	Precipitation (snow, rain, fog, etc.), temperature, wind speed and direction, solar radiation, relative humidity, etc.
Geology & Soils	Geomorphology	Stream / River Channel Characteristics	7	Monitor changes in geomorphology of stream/river bank and other riparian features in the ERMN.	Channel width, depth, and gradient; sinuosity; channel cross-section; pool frequency and depth; suspended sediment and bedload transport, particle size distribution, incision; gravel bars, islands, course woody debris, etc.
	Soil Quality	Soil Erosion and Compaction	11	Document condition and monitor trends in soil compaction and/or erosion in the ERMN.	Visitor impacts; Changes in thickness of topsoil, bulk density, etc.
		Soil Function and Dynamics	12	Document condition and monitor trends in soil function and dynamics in the ERMN.	Species composition and distribution with soil depth, soil respiration (mg CO2-C/m2/hr);Basic soil analysis of surface and near surface soil horizons, C:N ratio; contaminants.

Water	Hydrology	Surface Water Dynamics	13	Document the status and trend of surface water quantity in the ERMN, including flow in streams and rivers.	discharge (cfs or cumes), gauge/stage height, qualitative estimate of flow relative to bank full (stream); timing, extent, frequancy and duration of flood events; extent/volume inter-basin transfer; ice-scour.
		Wetland Water Dynamics	14	Document the status and trend of water quantity in vernal ponds and other wetlands.	timing, extent, duration of water inundation; drying time, etc.
		Groundwater Dynamics	15	Document the status and trend of groundwater quantity.	gauge/well level, recharge rates, etc.
	Water Quality	Water Chemistry - Core Parameters	16	Document status and trend in core water chemistry parameters in the ERMN.	4 core parameters (pH, DO, specific conductance, temp),
		Water Chemistry - Expanded Parameters	17	Document status and trend in an expanded suite of water chemistry parameters.	cations (Ca, Mg, Na, K), anions (PO4, NO2, Br, SO4, Cl, acid neutralizing capacity), turbidity, suspended sediments, BOD, COD, alkalinity, N & P compounds, chlorophyll a; VOCs, SVOCs, pesticides, PCBs, trace metals, etc. Other organic and inorganic substances;enteric viruses, fecal coliform bacteria (total coliform, enterococci, fecal streptococci groups, E. coli), Giardia, etc.
		Aquatic Macroinvertebrates	39	Document status and monitor trends in select indicator groups of aquatic macroinvertebrates.	Species richness, diversity, relative abundance; Family, genus, species composition and abundance; Indices of Biotic Integrity (IBIs)
		Aquatic Algae / Periphyton	42	Document status and monitor trends in composition, abundance and/or extent of select algae and other periphyton.	Community composition, abundance, extent; IBIs and indicator groups; AFDM, chlorophyll, enzyme activity, etc.
Biological Integrity	Invasive Species	Invasive plants, animals, diseases - status & trends	18	Document status and trends in established populations of invasive species and diseases, including response to treatment.	Distribution, occurrence, extent, etc. of existing invasive species and diseases (Hemlock wooly adelgid, gypsy moth, zebra mussel, asiatic clam; west nile virus, chronic wasting disease, rabies; Dogwood Anthracnose, sudden oak death, Beech-bark disease/beach scale, etc.
		Invasive plants, animals, diseases - early detection	19	Use monitoring data for early detection & predictive modeling of incipient invasive species and diseases.	Presence, location, extent, etc. of incipient invasive plants; predictive search models;
	Focal Species or Communities	Shrubland, Forest and Woodland Communities	20	Document status and trends in plant community composition, structure & dynamics in the ERMN.	species composition and abundance in overstory, understory and herbaceous layers; basal area & diameter classes; snags and course woody debris; condition & vigor classes; regeneration, etc.

Riparian Communities	28	Document trends in riparian vegetation community composition, structure, and dynamics in the ERMN.	Size, condition and context of riparian plant communities including Appalachian river scour/flat rock community.
Birds - Riparian Community	29	Document status and monitor trends in community composition, species abundance, and/or demographic rates of select riparian birds.	Community composition, abundance, and/or demographic rates of Louisiana Waterthrush; kingfishers; herons, and other riparian breeding Neotropical migrants
Mammals - Riparian Community	30	Document status and monitor trends in presence, distribution and/or abundance of select riparian mammals.	Presence, distribution, abundance, relative abundance and/or demographic rates of beavers, mink, otter, water shrew, northern flying squirrel and other riparian inhabiting mammals.
Birds - Breeding Bird Community	32	Document status and monitor trends in community composition, species abundance, and/or demographic rates of bird communities.	Community composition, abundance and/or demographic rates of communities or specific species of bird
Terrestrial Invertebrates	34	Document status and monitor trends in community composition, diversity, richness, abundance etc. of select terrestrial invertebrates	Community composition, diversity, richness, abundance etc. Pollinators, seed dispersers, defoliators, etc.
Freshwater Communities- Mussels	40	Document status and monitor trends in community composition and/or species abundance of freshwater mussels.	Community composition, abundance, distribution, age/sex classes, etc.
Freshwater Communities- Crayfish	41	Document status and monitor trends in community composition and/or species abundance of freshwater crayfish.	Community composition, abundance, distribution, age/sex classes, etc.
Freshwater Communities- Macrophytes	43	Document status and monitor trends in compostion, abundance and/or extent of select aquatic macrophytes.	Community composition, abundance, extent, etc.
Fishes - Stream Community	44	Document status and monitor trends in community composition, species abundance, and/or demographic rates of stream fishes.	Community composition, abundance, distribution, age classes, occupancy, etc.
Fishes - River Community	45	Document status and monitor trends in community composition, species abundance, and/or demographic rates of select riverine fishes.	Community composition, abundance, distribution, age classes, occupancy, etc. Endemic and non-native species.
Amphibians and Reptiles -Vernal Pond Community	46	Document status and monitor trends in community composition, species abundance, and/or demographic rates of vernal pond inhabiting amphibians.	Community composition, abundance, distribution, age classes, occupancy, persistance, etc.

		Amphibians and Reptiles - Streamside Salamander Community	47	Document status and monitor trends in community composition, species abundance, and/or demographic rates of streamside salamanders.	Community composition, abundance, distribution, age classes, occupancy, persistance, etc.
		Amphibians and Reptiles -	48	Document status and monitor trends in community composition, species abundance, and/or demographic rates of select reptiles and amphibians.	Community composition, abundance, distribution, age classes, occupancy, persistance, etc.
	At-risk Biota	T&E Species and Communities - State	49	Document status and monitor trends in select populations of State threatened, endangered, or at-risk species within the ERMN.	Status, distribution, population size, vigor, etc.
		T&E Species and Communities - Federal	50	Document status and monitor trends in select populations of Federally threatened or endangered species within the ERMN.	Virginia Spirea, Dwarf Wedgemussel, Bog Turtle, Bald Eagle, Indiana bat, Virginia Big-eared Bat status, distributions, population size, etc.
Human use	Point-Source Human Effects	Bioaccumulation	52	Conduct monitoring of toxicity levels in select species of fish, mammals and other species at risk.	Type (e.g. tissue Hg) and concentration level in selected species such as American Eels, Otters, etc.
	Visitor and Recreation Use	Visitor Use	54	Document changes in visitation and in spatio-temporal patterns of park use by visitors that impact select natural resources.	Type, level, spatial and temporal patterns of visitor use; road kills, vegetation trampling, climbing impacts.
Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use	57	Document changes in development and land conversion in and around ERMN park watershed boundaries.	Road density, housing density, recreational use intensity, impervious surface, deforestation, etc.
	Landscape Dynamics	Landscape Pattern	58	Document status and monitor trends in a suite of landscape metrics including area of dominant land cover types, patch shape, size, and connectivity, etc.	Area of dominant land cover types; Patch size distribution, distance between patches; from satellite imagery and aerial photography
	Energy Flow	Primary Production	59	Document status and trends in ecosystem primary production rates.	biomass production in aquatic or terrestrial systems, NDVI-derived vegetation growth index;
	Nutrient Dynamics	Nutrient Dynamics	61	Document status and trends in key ecosystem nutrient cycles.	C, N, P, K dynamics in terrestrial or aquatic systems


A Conceptual Diagram of Terrestrial Ecosystems
1
2
3
4
5
MANAGEMENT ISSUES
Housing/Urban development
Recreation and Visitor Use
Industry and other polluters
Native invasive species
(i.e. white-tailed deer)
Exotic Invasives (i.e. gypsy moth)
Agriculture
Park Boundary
RESOURCES
Early Successional Habitat
Forested Wetlands and Vernal Pools
Breeding Bird Communities
Terrestrial Invertebrates
Amphibians
Terrestrial Forests
INPUTS/IMPACTS
Damaged Plants
Atmospheric pollutants
(i.e. Hg, P)
Ozone
Reduced Biodiversity
Soil compaction and erosion
Eastern Rivers and Mountains Network

Terrestrial Ecosystem Conceptual Model Narrative

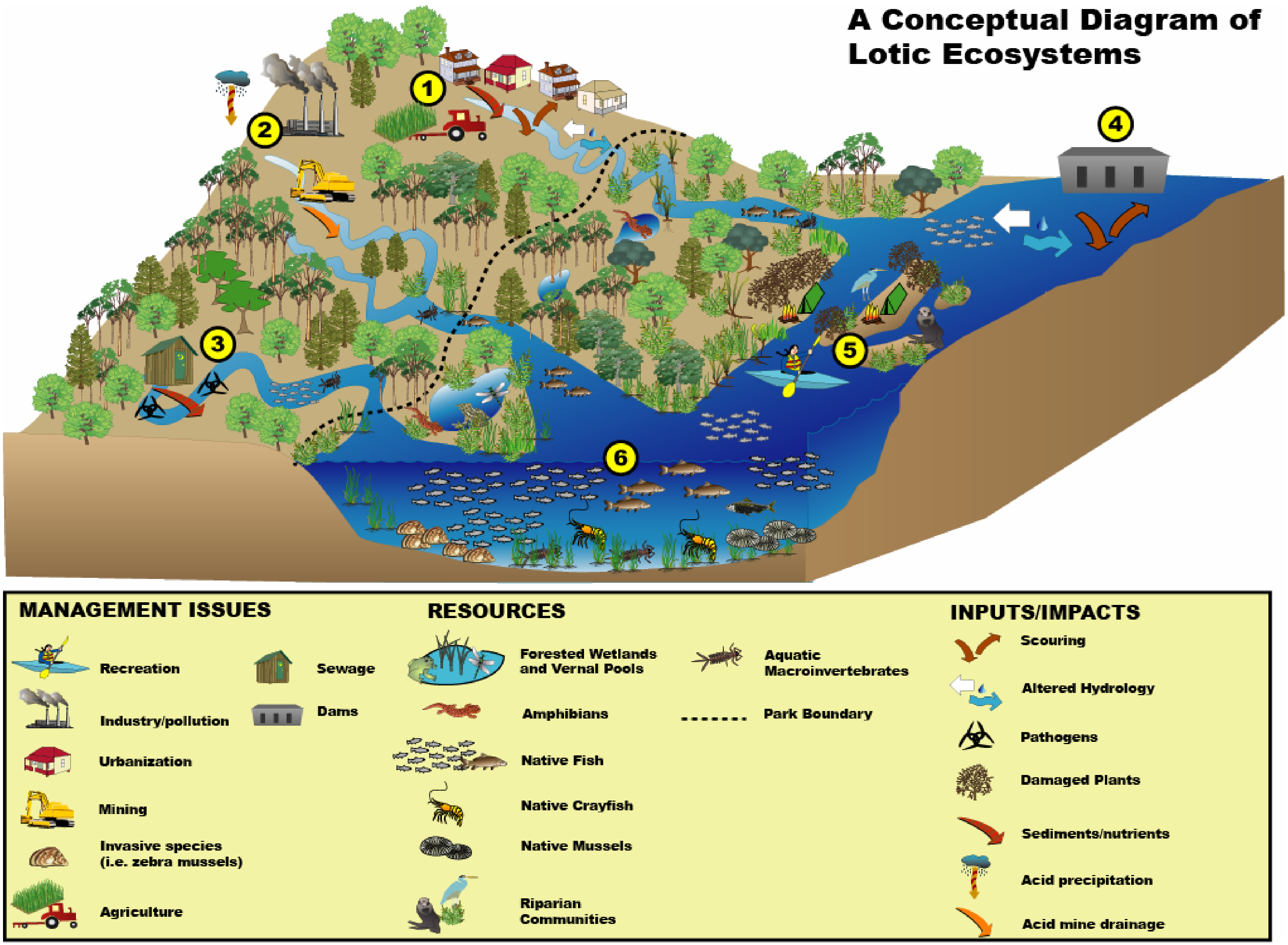
1. High levels of atmospheric ozone concentration (VS1) cause foliar damage to sensitive plant species limiting the plant's ability to photosynthesize. Loss of ozone-sensitive species or gentoypes reduces overall biodiversity and may result in the loss of other rare species or communities (VS49, VS50).

2. Wet and dry deposition of atmospheric pollutants (VS2), including acids, nutrients and toxins can affect numerous ecosystem processes including nutrient dynamics (VS61), litter and soil dynamics (VS12), and forest vegetation dynamics (VS20). Indirect effects of pollutants may enable invasive species (VS18, VS19) and result in the loss of rare species/communities (VS49,VS50), including terrestrial invertebrates (VS34) due to habitat alteration or direct toxicity. Amphibian species (VS46, VS47, VS48) appear to be especially sensitive to water-borne pollutants and some fish and mammal species have shown to bioaccumulate some toxins (VS52).

3. Changes in landscape pattern (VS57) and land cover and use (VS58) are primarily the direct result of urbanization, fragmentation, and pollution. Roads have a particularly profound fragmenting effect on terrestrial ecosystems and changes in landscape pattern can alter habitat for breeding birds (VS29, VS32), terrestrial invertebrates (VS34), mammals (VS30) and forested wetlands (VS46). Because human activities are often involved in the introduction of invasive species, the pattern of introduction of invasive species (VS18, VS19) often follows patterns of human activity (transportation corridors, housing developments, etc.) Finally, biological productivity (VS59) and nutrient dynamics (VS61) are specifically linked to landscape pattern.

4. Excessive visitor use (VS54) along trails, campsites and river stops can damage sensitive plant and animal communities (VS49, VS50) such as cliffline communities and riparian plant communities (VS28) and can alsocause soil erosion and compaction (VS11)

5. Current and incipient invasive plant and animal species (VS18, VS19) can alter native community structure (VS20, VS28, VS34) decreasing overall biodiversity and potentially altering productivity (VS59) and nutrient cycling (VS61).


A Conceptual Diagram of
Lotic Ecosystems
1
2
3
4
5
6
MANAGEMENT ISSUES
Recreation
Sewage
Industry/pollution
Dams
Urbanization
Mining
Invasive species
(i.e. zebra mussels)
Agriculture
RESOURCES
Forested Wetlands
and Vernal Pools
Aquatic
Macroinvertebrates
Amphibians
Park Boundary
Native Fish
Native Crayfish
Native Mussels
Riparian
Communities
INPUTS/IMPACTS
Scouring
Altered Hydrology
Pathogens
Damaged Plants
Sediments/nutrients
Acid precipitation
Acid mine drainage

Lotic Ecosystem Conceptual Model Narrative

1. Headwater urbanization, agriculture, and other changes in landscape pattern (VS57) and land cover and use (VS58) alter water quality (VS16, VS17) and quantity (VS13, VS14, VS15) potentially causing changes to stream and river geomorphology (VS7). These impacts, in turn, can impact benthic macroinvertebrates (VS39), fishes (VS44, VS45), streamside salamnder communities (VS47), aquatic periphyton (VS42), freshwater mussels (VS40) and crayfish (VS41)

2. Wet and dry deposition of atmospheric pollutants (VS2) including acids, nutrients and toxins can affect numerous ecosystem processes including nutrient dynamics (VS61) and overall water quality (VS16, VS17). Indirect effects of pollutants may enable invasive species (VS18, VS19) and result in the loss of rare species/ communities (VS49, VS50) due to habitat alteration or direct toxicity. Amphibian species (VS46, VS47, VS48) appear to be especially sensitive to water-borne pollutants and some fish and riparian mammal species (VS30) have shown to bioaccumulate some toxins (VS52).

3. Treated and untreated sewage (VS17) effluent inputs nutrients and pathogens into streams.

4. Dams from upstream reservoirs alter hydrologic flow (VS13) and water quality (VS16, VS17) potentially impacting benthic macroinvertebrates (VS39), fishes (VS44, VS45), aquatic periphyton (VS42), freshwater mussels (VS40), crayfish (VS41) and riparian communities (VS28).

5. Excessive visitor use (VS45), campsites and river stops can damage sensitive plant and animal communities (VS49, VS50) such as riparian plant communities (VS28).

6. Current and incipient invasive plant and animal species (VS18, VS19) can alter native fish (VS44, VS45), crayfish (VS41), aquatic macrophytes (VS43) and riparian plant (VS 28) community structure decreasing overall biodiversity and altering aquatic productivity (VS59) and nutrient cycling (VS61).

Level 1 ► Air and Climate
Level 2 ►Air Quality
Level 3 ► Ozone (VS01)

***Brief Description*:** "Air chemistry – Ozone" refers to the concentration of, and trends in, ozone in the ambient air of National Park Service lands in the Eastern Rivers and Mountains Network (ERMN). In addition, the vital sign includes ozone effects on park natural resources; specifically, ozone-induced foliar injury of plant species. The amount of ozone in the atmosphere is a primary predisposing factor affecting ecosystem health, whereas the symptoms of ozone injury displayed by sensitive plant species can be viewed as an indicator of ecosystem health relative to ozone (Chappelka and Samuelson 1998).

Significance/Justification: The northeast and mid-Atlantic regions of the United States experience high levels of atmospheric ozone due to emissions of ozone precursors, i.e., nitrogen oxides and volatile organic compounds, from the densely populated region as well as from upwind in the heavily industrialized Ohio River Valley. Because ozone is a regional pollutant, elevated concentrations occur throughout the entire ERMN. Ozone concentrations in many of the ERMN parks likely reach levels that threaten human health. From a natural resource standpoint, ozone-induced foliar injury, or necrosis, affects a plant's ability to carry out photosynthesis and to perform necessary physiological processes such as transpiration and mineral uptake. Therefore, plants with acute ozone injury are unable to efficiently use resources such as light, water and mineral nutrients. Ultimately, ozone injury could affect plant health and fecundity leading to a reduction in competitive ability. Loss of ozone-sensitive species may result in the loss of critical habitat or food resources and potential reduction in species diversity. Documentation of ozone-induced foliar injury on species with known sensitivity to ozone can serve as an indication that ozone concentrations are reaching levels of concern in network parks.

Proposed Metrics: To determine compliance with the present Environmental Protection Agency (EPA) human health-based air quality standard for ozone of 85 parts per billion (ppb), the proposed monitoring metric is the average hourly value of the 4^{th} highest 8-hour ozone concentration over a three-year period. A second metric will be used to assess ozone threats to vegetation. This metric is the SUM06, the running 90-day maximum sum of the 0800-2000 hourly concentrations of ozone equal to or greater than 0.06 parts per million (ppm), which represents a cumulative exposure dose of ozone to plants. To evaluate the occurrence and extent of ozone-induced foliar injury, the ERMN would follow guidance and monitoring protocols currently under development by the NPS Air Resources Division (ARD). The ARD protocols will incorporate monitoring techniques and metrics used by a number of researchers into a step-by-step, peer-reviewed document.

***Prospective Method(s) and Frequency of Measurement*:** A review of monitoring databases indicates that, with the exception of the Upper Delaware, all ERMN parks have an EPAapproved ozone monitor within 35 km (Air Quality Summary included in the ERMN Draft report for Long-Term Ecological Monitoring, Phase 1). Given the expense of installing and operating an ozone monitoring station, and the higher priority of other vital signs, the ERMN intends to rely on the data collected at existing sites to represent ambient ozone status and trends in network parks. An ozone injury risk assessment (Kohut 2004) indicates a “moderate to high risk of ozone injury to sensitive vegetation” exists in all ERMN parks. The ERMN may choose to initiate an ozone foliar injury monitoring program, particularly if the monitoring could be coordinated with other types of vegetation monitoring. The methodology and frequency of measurement would be determined at a later date, but would follow the foliar injury monitoring guidance under development by the ARD.

***Limitations of Data and Monitoring*:** Ambient ozone concentrations will be based on interpolated data since no ERMN parks have on-site ozone monitors. However, due to the regional nature of ozone, the interpolated values will likely be representative of ozone concentrations in ERMN parks. There are a number of limitations to foliar injury surveys. First, ozone concentration is not directly correlated with the amount of injury on a plant. Second, physiological effects can occur with or without the presence of foliar injury, and vice versa. Third, environmental factors, such as drought stress, can influence ozone uptake and resulting injury. Finally, only a handful of species have been tested for ozone sensitivity, so the sensitivity of most species, including rare and endangered plants, is unknown. A major limitation of ambient ozone and effects monitoring is the fact that the sources of ozone precursors are not directly controllable by the NPS, thus restoration of lost or damaged ecosystems may be difficult or impossible, especially if ozone levels continue to rise.

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***Related Environmental Issues and Linked Vital Signs*:** Atmospheric ozone directly affects a number of ecosystem attributes, especially related to biodiversity and vegetation communities. Indirect effects may be far-reaching and could include impacts such as enabling invasive species, loss of focal species or communities, effects on terrestrial invertebrates when key habitat is altered, etc. (Edwards Huber and Wood 2004).

***Overall Assessment*:** Atmospheric ozone can have significant impacts, both direct and indirect, on a number of ecosystem processes. Although many regional data currently exist on atmospheric ozone levels, there is no site-specific monitoring at ERMN parks. However, the regional monitoring data are likely adequate. Monitoring the presence of ozone foliar injury symptoms on sensitive vegetation would provide an indication that ozone levels are reaching concentrations that are a threat to park resources. Ozone injury monitoring data could be used to inform and educate the public about the consequences of elevated ozone levels. Unfortunately, ozone results from a number of anthropogenic sources located, for the most part, outside park boundaries, and thus not under the control of the NPS. Therefore, restoration of ozone damaged ecosystems may be difficult or impossible. While installing ambient ozone monitors in ERMN parks would be prohibitively expensive, ozone injury monitoring could potentially be relatively inexpensive, especially if the monitoring could be conducted in conjunction with other network vegetation monitoring activities.

Level 1 ► Air and Climate
Level 2 ►Air Quality
Level 3 ► Wet and Dry Deposition (VS02)

***Brief Description*: "**Deposition" refers to the deposition of, and trends in, pollutants that are carried in ambient air and deposited on National Park Service lands in the Eastern Rivers and Mountains Network (ERMN). Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through wet deposition (rain or snow), occult deposition (cloud or fog), or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Although it is important to know total deposition, (i.e., the sum of wet, occult, and dry deposition) to park ecosystems, often only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. through the National Atmospheric Deposition Program (NADP). Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems. For the most part, atmospheric pollutants are primary predisposing and inciting factors affecting ecosystem health.

***Significance/Justification*:** All of the ERMN parks occur within or downwind of areas of the central and eastern United States that have a significant influence from industrialization and power generation. Vehicular burning of fossil fuels in the densely populated region also contributes much to the atmospheric pollution load. These pollutants have potentially sweeping effects on the entire ERMN (Lovett 1994). Deposition effects are manifested in a variety of ways, depending on the pollutant. Direct effects include foliar necrosis and dieback in plants. In other cases, pollutants may be directly toxic to plants, animals or microorganisms. However, indirect effects that result, for example, from soil acidification and its effect on mineral cycling may be more significant in the long term. Atmospheric pollutants potentially affect resources such as water and mineral nutrients. The long-term effects, such as altered litter decomposition, micro-flora and fauna, and altered nutrient cycling pose major threats to the health, fecundity and sustainability of the ecosystems and lead to an overall loss of species diversity.

***Proposed Metrics*:** Due to the relative lack of regional data on dry and occult deposition, the ERMN will use wet deposition data reported as kilograms per hectare per year (kg/ha/yr).

***Prospective Method(s) and Frequency of Measurement*:** The ERMN will rely on wet deposition data measured at NADP sites in and near network parks. NADP measures a comprehensive suite of anions and cations; deposition rates of total wet sulfur (S) and total wet inorganic nitrogen (N) (ammonium plus nitrate ions) are included in the summaries.

***Limitations of Data and Monitoring*:** Ideally, the ERMN would evaluate total deposition, i.e., wet plus dry plus occult, to assess the threat to resources. Realistically, only wet deposition data are available. Wet deposition values will be based on interpolated data for most ERMN parks since only one park has an on-site NADP monitor. Because of meteorology and intervening terrain, interpolated deposition values may be somewhat different than those that would be based on on-site data. Atmospheric pollution is often a problem of regional, even global proportions, therefore it may be difficult or impossible to mitigate. Moreover, the sources of pollution are outside the parks and, therefore, cannot be controlled by the NPS.

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Related Environmental Issues and Linked Vital Signs: Atmospheric pollutants directly affect a number of ecosystem processes. In particular, soils can absorb and accumulate pollutants, altering nutrient cycling. Acidified soils have lower base saturation and therefore lower fertility resulting in reduced bio-productivity. Runoff, throughfall and direct input to streams and lakes can result in impacts to aquatic systems as well as to terrestrial systems which can lead to loss of sensitive species.

Overall Assessment: Atmospheric deposition of sulfur and nitrogen compounds is prevalent in the EMRN region and can affect numerous ecosystem processes, including nutrient cycling, litter dynamics and regeneration. Indirect effects of pollutants may be the enabling of invasive species and the loss of T&E species due to habitat alteration or direct toxicity. Amphibian species appear to be especially sensitive to water-borne pollutants. The ERMN can rely on the existing network of NADP monitors for wet deposition data, but because the NPS cannot control sources of pollution outside park boundaries, mitigation and reclamation of damaged ecosystems will be difficult.

Level 1 ► Air and Climate
Level 2 ►Weather and Climate
Level 3 ► Weather and Climate (VS04)

Brief Description: Weather and climate are factors that have a direct effect on the health and competitive ability of long-lived perennial organisms like trees. Plants of a given species possess the genetic potential to exist within a particular range of temperature and moisture conditions, known as "cardinal limits", (Hicks, 1998). Furthermore, species are most competitive at certain conditions that are near the "ecological optimum" for their physiological processes. One of the most critical and controversial issues in the scientific community today is the prospect of global climate change, specifically global warming. For example, Overpeck , Barlein and Webb (1991) propose that the global climate could warm by an average of 1.5- 4.5 degrees C by the end of the twenty-first century. This, in turn, could lead to the migration of southern species to the north (Solomon and Kirilenko, 1997) as well as local extirpation of species such as red spruce in the southern Appalachians (Adams et. al. 1985). It is important to monitor the climatic changes in the ERMN and to link these changes to the health, productivity and fecundity of sensitive and ecologically important species.

Significance/Justification: Weather and climate are predisposing factors affecting health and vigor of organisms and communities. When organisms are affected by climate change they are unable to efficiently use resources such as light, water and mineral nutrients, and may become competitively disadvantaged relative to other species in the community. Climate change will affect the health and fecundity of organisms leading to a reduction in competitive ability. Loss of sensitive species may result in the loss of critical habitat and potential reduction in species diversity. Because of the apparent global climate change that is predicted to continue for many decades, species that live at suboptimal fringes of their range are most at risk. The National Park Service is mandated to preserve unique biological resources in its parks, therefore it is imperative that communities and organisms that are sensitive to global change in the parks be monitored carefully. Such species will serve as indicators of impact (De Groot, Ketner and Ovaa, 1995). Mahon (2004) provides lists of plants, vertebrates and communities of special concern in the New River Gorge (NERI). Some of these species may be among the first to suffer from the effects of global climate change. Monitoring these species will permit the National Park Service to take action before non-sensitive organisms are affected.

Proposed Metrics*: *Prospective Method(s) and Frequency of Measurement: Metrics such as species importance values and indices to health and vigor of certain species deemed to be sensitive to climate change could be used to show impact. In addition, measures of species diversity can be used as potential indicators of climate-related problems. It is also important to track weather and climate in the parks, although the National Oceanic and Atmospheric Administration (NOAA) data may be adequate for this purpose without additional in-house tracking. Weather data that are important include daily, monthly, seasonal and annual averages for maximum and minimum temperatures, and precipitation. In addition, growing season length is important.

***Limitations of Data and Monitoring*:** One limitation to monitoring sensitive species is determining which ones are actually the best candidates as indicators. Secondly, if species are threatened or endangered, they will be difficult to find. In addition, taking measurements on T&E species may in itself cause stress to the species and therefore may not be advisable. Finally, if indeed global climate change is occurring, it is not under the control of the NPS, thus restoration of lost or damaged ecosystems is probably not possible.

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Related Environmental Issues and Linked Vital Signs: Weather and climate directly affect a number of other ecosystem attributes, especially related to sensitive and T&E species, biodiversity, etc. Because climate does not act in a vacuum, other vital signs such as levels of atmospheric pollution (VS1, VS2, VS3) may interact with climate to affect organisms. Indirect effects may occur such as the enabling of invasive species and loss of focal species or communities.

Overall Assessment**:** Climate plays a fundamental role in terrestrial ecosystems. Therefore climatic changes have the potential to bring about substantial changes in the functional role of organisms, therefore changes in communities. Climate change appears to be a global phenomenon, caused by the accumulation of greenhouse gases in the atmosphere and is impossible to control at a local level. Therefore, restoration of climate-altered ecosystems may be difficult or impossible. However, good climatic data exist through the NOAA data bases and is relatively inexpensive to the NPS. On the other hand, monitoring ecosystems to determine whether or not ecosystem changes are occurring in response to changing climate may be very difficult and expensive.

Level 1 ► Air and Climate
Level 2 ► Soil Quality
Level 3 ► Soil Erosion/Compaction (VS11)

Brief Description**:** “Soil erosion/compaction” refers to processes that occur in which residual soil is compacted and/or lost from a site, usually through the action of water. Compaction is the effect that takes place when soil is subjected to heavy or repeated pressure, therefore reducing its pore space and increasing its bulk density (Shestak and Busse 2005). Soil erosion literally takes the soil, and its included nutrients and water-holding capacity, away from a site and therefore denies plants and animals resources such as oxygen, mineral nutrients and water. Compaction also reduces available oxygen and restricts root growth in the soil which, in turn, may result in de-vegetation of the compacted area, which is often followed by erosion (Deluca et. al. 1998). These are two of the most destructive processes relating to soils, and soils form the basis for plant life in terrestrial communities. The USDA, Natural Resource Conservation Service (NRCS) and the Soil Science Society of America (SSSA) provide standard methods for assessing soil loss and compaction that can be applied to high use areas in the EMRN parks. Soil erosion/compaction can be a contributing factor to altered ecosystem health.

Significance/Justification**:** Soil forms the basis for terrestrial ecosystems. It is a complex mixture of organic and inorganic fractions and provides support as well as minerals, water and oxygen to plants (Powers et. al. 2004). Particularly in high-use areas of the ERMN parks, soils are at risk for compaction and erosion, especially in heavily traveled areas such as trails, overlooks and historic sites (Deluca et. al. 1998). Ironically, the very reason these sites have significance is because people find them interesting and unique. But overuse or poorly planned use may destroy the very resources that make the parks unique in the first place. Compacted soils often are difficult for plant roots to penetrate and have reduced aeration and poor water holding capacity. This may lead to the loss of mesofauna and vegetation (Battigelli et. al 2004), which, in turn, leads to erosion and soil loss. Over time, compaction and erosion will degrade the site leading to reduced diversity, bio-productivity, regeneration, health and fecundity of the plant community. This will adversely impact the fauna of the system as well. Once soil has eroded from a site, it often appears as sediment in nearby streams, thus creating another environmental problem.

Proposed Metrics**:** The NRCS uses the Universal Soil Loss Equation to predict soil loss from eroded sites as weight of soil lost per unit area of land. For soil compaction, the standard measure is bulk density, expressed as weight per unit volume of soil.

Prospective Method(s) and Frequency of Measurement**:** Soil erosion can be measured by placing stakes in the soil and periodically measuring the exposed height of the stake to indicate the amount of soil lost. Erosion stakes should be strategically placed in high use areas such as paths and trails, picnic areas, overlooks and historic sites. To serve as a control, stakes should also be placed in low-use areas as well. The erosion stakes should be measured at least 3 times each year, during the high-use season (usually summer into fall). In addition, soil bulk density measurements should be taken at the same high-use sites. There are several methods for bulk density measurement, including some that require removal of soil for weight and volume determination, and others that use a probe to determine the resistance of the soil to penetration. For the latter, the method is not well suited to soils with high rock content. Bulk densities should be taken at least once per season (preferably in the fall), and as with the erosion measurement, control sites should be included that are outside the high traffic areas.

***Limitations of Data and Monitoring*:** As with any data that are acquired by sampling, the validity of the data is a function of the adequacy of the sampling system. Using a large number of samples is always better than a small sample. However, if the experimental unit is a single site at a park, the number of samples to adequately represent that site may be quite large, as opposed to the case where soil erosion/compaction data are intended to represent the whole park or the entire ERMN system. Decisions will have to be made by the managers as to which scenario they wish to monitor, and ultimately the limitation may be determined by how many samples they can afford to collect.

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***Related Environmental Issues and Linked Vital Signs*:** Soil productivity is directly related to soil erosion and compaction. The soil fauna and flora as well as nutrient cycling are affected by compaction and erosion. Bio-productivity and regeneration may also be affected. Certain T&E species could be directly affected by these conditions, and soil that is lost from a terrestrial site may end up as silt and sediment in a nearby aquatic system.

***Overall Assessment*:** Soil is the primary medium for plant growth, providing support as well as oxygen, minerals and water for plant growth. Compaction and erosion are most likely to occur in and around high-use areas of the ERMN parks, and a monitoring system to detect levels of erosion and compaction should focus on these sites. Depending on the chosen experimental unit (site, park, system), the sampling scheme may be rather elaborate and collecting and processing samples could be labor-intensive and time-consuming. If such is the case, proper soil compaction/erosion data could be expensive to collect and analyze. But, considering the damage that may be occurring due to over use or improper use, the investment may be worth it. Soil erosion/compaction is an issue that is within the direct control of park managers and preventative or remedial activities such as restricting access and rerouting or paving trails can have immediate benefits to the ecosystem.

Level 1 ► Geology and Soils
Level 2 ► Soil Quality
Level 3 ► Soil Function and Dynamics (VS12)

Brief Description**:** "Soil function and dynamics" includes several important biological and chemical processes that take place in the soil. These processes are key elements in soil fertility, nutrient cycling and soil structure. Soil biota includes everything from small mammals (chipmunks, etc.), insects such as ants (Wagner, et. al. 1997), invertebrates (Mudrick et. al. 1994) and microorganisms such as fungi and bacteria. These organisms are involved in a variety of processes, including organic decomposition (Tate 1987), mineralization, and fixation. Soil organic matter (SOM) presence and dynamics are a function of several conditions and processes. For example, conifer forests often contain larger pools of undecomposed litter than do hardwood forests in similar climates, owing to the lower palatability of conifer needles to organisms involved in the decomposition process. Soil chemistry has been widely examined in agricultural systems and it is well known that deficiencies in required nutrient elements can restrict growth and health of plant communities. In recent years, it has also become apparent that excesses in minerals such as nitrogen and sulfur can lead to degraded forest ecosystems as well (Johnson et. al. 1999). Soil biota, organic matter and chemistry are generally indicators of ecosystem health.

Significance/Justification: Soil forms the basis for terrestrial ecosystems. It is a complex mixture of organic and inorganic fractions and provides support as well as minerals, water and oxygen to plants (Powers et. al. 2004). Soils which are not within normal ranges of variability with regard to biotic and chemical properties may also result in reduced diversity, bio-productivity, regeneration, health and fecundity of the plant community growing on that soil. This will adversely impact the fauna of the system as well. Anthropogenic factors such as air pollution, wet/dry deposition, global climate change and soil compaction and erosion caused by overuse can lead to altered soil properties, which in turn can affect soil biota (Hassink et. al. 1993). Changes in soil properties are reversible, but once a soil is damaged beyond a certain threshold, recovery will be slow, due to the feedbacks that exist between soil condition and the biotic communities that exist within soils. It is imperative that soils be monitored closely to detect changes before they become excessive.

Proposed Metrics**:** Living biomass in soils can be assessed in terms of total amount present or diversity of species present. The former is much simpler to measure since standard tests such as measuring rates of soil respiration can be used (mg CO_2-C/m^2/hr). For species diversity, actual counts of various guilds or taxa of soil organisms will be required to determine richness and abundance of organisms. Soil organic matter (non-living biomass) can be inventoried by using standard tests such as loss on ignition, and organic matter is usually expressed as weight per soil mass or percent. Finally, soil nutrient elements are usually expressed as parts per million or for acidity, as pH.

Prospective Method(s) and Frequency of Measurement: Soil sampling in the spatial dimension should be conducted so as to sample the important soil series represented in the ERMN parks.

The first step is to access the soil survey information from the USDA Natural Resource Conservation Service (NRCS) and set up a stratified sampling scheme in which soils are sampled within each series represented. Regarding the temporal scale, it would be advisable to return to the same areas year after year in order to limit variability that might occur due to micro-scale phenomena, such as forest cover type, aspect, hydrology, etc. Sampling should be conducted at least once per season (during the active growing season). Because soil biota fluctuate seasonally (Mudrick et al 1994) it is important to sample at approximately the same time of year. It is also important to account for other micro-environmental conditions (slope aspect, forest cover type, stand age, current and recent weather, etc.) The Tullgren method of extraction can be used to inventory microarthropods (Edwards and Fletcher, 1971). The NRCS and the Soil Science Society of America (SSSA) provide standard methods for assessing soil physical and chemical properties that can be applied to soils collected from EMRN parks.

***Limitations of Data and Monitoring*:** The validity of soils data that are acquired through sampling is a function of the adequacy of the sampling system. The land area of some of the ERMN parks is quite large and there are probably many soil series represented in these larger parks. The number of samples required to provide a pre-determined level of accuracy can be computed, but a preliminary sample must be taken in order to calculate an estimated variance for the variables of interest. A large number of samples will always provide more accurate results than a small sample. However, if the experimental units are the soil series within a park, the number of samples to adequately represent that park may be quite large, especially if a large number of soil series occur. Under normal circumstances, where resources are limited, managers will have to decide how they can allocate their resources to best accommodate their needs. For example, if particular sites or soils are known to be especially sensitive, it may be prudent to target these for soil sampling, foregoing the sampling of less sensitive sites.

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***Related Environmental Issues and Linked Vital Signs*:** Soil productivity is directly related to soil chemistry and organic matter content. The soil fauna and flora as well as nutrient cycling (VS61) are affected by soil properties. Bio-productivity (VS59) and regeneration may also be affected. Air chemistry (VS2) and weather and climate (VS4) can profoundly affect soil properties as can the geologic material from which soils are formed. Indeed, there are many interactions between soils, atmosphere and the biosphere, and the complexity of these interactions makes it difficult to predict how a particular soil will respond to external changes.

***Overall Assessment*:** Soil is the primary medium for plant growth, providing support as well as oxygen, minerals and water for plant growth. Soil chemistry, organic content and micro-flora and fauna are properties that significantly affect productivity and the structure of the plant and animal community that exists in a particular ecosystem. Monitoring the parameters of soil that are important to the maintenance of a healthy and productive ecosystem is critical to management of that ecosystem. On the other hand, the chemical, physical and biological composition of soils is very dynamic, with strong seasonal trends. Therefore sampling must be standardized so as to avoid unwanted variation. Furthermore, there may be a number of different soils, with different properties, distributed over a relatively small spatial scale, which confounds the sampling process. Depending on the chosen experimental unit (soil series, site, park, system), the sampling scheme may be rather elaborate and collecting and processing samples could be labor-intensive and time-consuming. If such is the case, proper data would be expensive to collect and analyze.

Level 1 ► Biological Integrity
Level 2 ► Invasive Species
Level 3 ► Invasive Plants, Animals, Diseases – Status and Trends (VS18)

Brief Description: "Invasive plants, animals, diseases – status and trends" is a very broad subject, including 1) invasive plants and animals whose primary effect is displacement of native species and 2) species of exotic insects, animals or pathogens that attack and cause injury or death to native species. Examples of the former are tree-of-heaven, purple loosestrife and garlic mustard, whereas examples of the latter include nutria, beech bark disease, gypsy moth, chestnut blight and hemlock woolly adelgid. An abundance of invasive plants and animals is often associated with disturbed or degraded ecosystems (Burke and Carino 2000); therefore their presence serves as an indicator of ecosystem health. On the other hand, invasive species, including insect and disease pests, can dramatically alter an ecosystem (serving as an inciting factor for ecosystem decline), thus directly affecting processes such as succession, regeneration and mineral cycling. Furthermore, the altered ecosystem state may result in a system that is unhealthy, has lower diversity and having reduced fecundity of native species. Invasive species, including insects and diseases, have resulted in dramatic historic changes to numerous ecosystems in North America, including the ERMN area. Examples include chestnut blight, which has all but eliminated a species that once defined much of the mid-Atlantic region, and gypsy moth, which has caused extreme damage and major ecosystem changes throughout the region. The recent invasion of the hemlock woolly adelgid indicates that the potential risk from invasive organisms remains significant.

Significance/Justification**:** Native plants and animals, that make up a particular ecosystem have co-evolved over millions of years, therefore native ecosystems have developed a state of dynamic equilibrium. The introduction of non-native species into a system can upset this balance. Because of the globalization of human activities, including travel, shipping and deliberate species introduction for food and agricultural purposes, many species have been moved from their native ranges and have been introduced to exotic environments around the world. In most cases, these species have been unsuccessful or have blended into the local environment with minor impacts. But for some species, their introduction has led to their becoming "invasive". This term refers to the condition that exists when a non-native plant or animal becomes highly aggressive in its new environment and causes habitat destruction, replacement of native species or results in damaging outbreaks. National parks are especially vulnerable to species invasion because of the large number of visitors who enter the parks and serve as potential vectors of invasive organisms. At the forest community level, resources such as light, mineral nutrients and water are affected when invasive species either displace or attack and kill native species. Invasive organisms can bring about alterations in species composition, bio-productivity, regeneration and nutrient cycling, changing the diversity, vigor and fecundity of the ecosystem. The direct effects of an invasion include species displacement, infestation, and mortality of host species, but indirect effects such as shifts in species composition, altered nutrient cycling, modified temperature and light regimes often have more profound impacts than the direct effects (Kizinski et.al. 2002). The introduction of organisms has resulted in greater and more lasting ecosystem damage than virtually anything brought about by humans in recent history (Pimentel et. al 2000).

Proposed Metrics**:** In situations where an invading organism has not yet fully colonized a suitable habitat, the metric chosen to describe the colonization is usually the rate of advancement of the infestation or killing front. In the case where a non-invasive form of an organism precedes the invasive or reproductive stage (such as is the case when male gypsy moths precede the flightless female into an non-infested area), the presence and numbers of male moths can serve as an indication of the potential for invasion by reproductive populations. In areas where infestation or invasion has already occurred, the numbers of invading organisms per unit area or the proportion of the suitable habitat that has been colonized can be a valuable metric. Finally, the presence and impact of an insect or disease is often measured by the number or proportion of hosts that are colonized or killed. This would be particularly useful where the populations of invading organisms are very large and difficult to measure and the value of the host is great, for example with beech bark disease and hemlock wooly adelgid (Morin et. al. 2005) .

Prospective Method(s) and Frequency of Measurement**:** Surveys of damaging insect and diseases of forest ecosystems are conducted by federal agencies such as the USDA Forest Service as well as by state agencies such as the West Virginia Department of Agriculture, Plant Industries Division. For newly-introduced organisms that are potentially damaging, records and surveys are conducted by the USDA, Animal and Plant Health Inspection Service. Before any in-house programs are undertaken by the ERMN, this information should be investigated to determine whether or not it meets the needs of the NPS. Furthermore, hazard rating systems that have been developed, especially in the case of insects and diseases, may be useful in determining whether or not a particular park is likely to have a problem with an invading organism. Once it is determined that a need exists for additional on-site surveys for an invading organism, the appropriate sampling scheme should be developed and tailored to the specific situation. With a problem as broad and diverse as invasive plants – animals, insects and diseases, surveys will need to be developed that are capable of detecting damaging populations and that fulfill the needs of the ERMN.

Limitations of Data and Monitoring**:** Perhaps the greatest limitation of monitoring for invasive organisms is the sheer magnitude of the task. The ERMN parks occupy extensive areas of land and are situated in areas with large and remote forested components. Organisms can quickly spread from non-system lands onto parks. Invasive organisms can persist below detection levels and rapidly explode into outbreaks when favorable conditions occur. Data collected only on NPS lands will be of limited value in predicting the ambient population levels and therefore may not be useful in preventing spread of organisms from adjacent ownerships. It incumbent upon the NPS to choose carefully which organisms to focus on, concentrating on those most likely to do significant damage to the parks and to utilize data collected by other agencies, whenever possible.

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***Related Environmental Issues and Linked Vital Signs*:** Species invasion could be linked with Air and Climate, such that an altered climatic regime may predispose a site to being invaded. Invasive species may displace plants and/or animals from unique natural communities, and this is especially true for T&E species, which may be living close to the limits of their existence in the absence of aggressive competitors.

***Overall Assessment*:** Invasive plants, animals, diseases – status and trends is a very broad topic, and includes both exotic invasive species that displace natural species or communities as well as insects and diseases that injure or kill native species. These agents are, however, some of the most damaging of those affecting current terrestrial ecosystems. Their spread is directly related to human activities, either deliberate, accidental or unintentional. This makes them all the more significant in National Parks where human visitation rate is high. Surveys of invasive organisms, damaging insects and diseases are routinely conducted by several federal and state agencies within the ERMN and data from these surveys is public domain, therefore inexpensive or free to acquire (USDA, Forest Service 1993). But for certain key species, the NPS may wish to develop their own on-site survey data. The decisions regarding which species and how to sample for them should be weighed carefully, since valid surveys may be difficult, expensive and time consuming.

Level 1 ► Biological Integrity
Level 2 ► Invasive Species
Level 3 ► Invasive/Exotic Plants, Animals and Diseases – Early Detection (VS19)

Brief Description**:** “Invasive species- early detection” involves having timely warnings if and when invasive species move into an ERMN park. Invasive plants and animals may displace native species and, 2) exotic insects, animals or pathogens can attack and cause injury or death to native species, and 3) exotic invasive species may alter the habitat for native plants and animals, making it unsuitable to them. Examples of aggressive invaders are tree-of-heaven, whorled loosestrife and garlic mustard, whereas examples of destructive or pathogenic invaders are beech bark disease, gypsy moth, chestnut blight and hemlock wooly adelgid. An example of a habitat-altering invader is the South American rodent, nutria. Probably thousands of new species have been introduced into the United States, either by accident or on purpose. Most of them, in the absence of cultivation and tending, fail to become established, but occasionally a species becomes invasive. In fact, the invasiveness of a particular species can, to some extent, be predicted (Burke and Grime 1996). An abundance of invasive plants and animals is often associated with disturbed or degraded ecosystems (Daehler and Carino 2000); therefore their presence serves as an indicator of ecosystem health. On the other hand, invasive species, including insect and disease pests, can dramatically alter an ecosystem (serving as an inciting factor for ecosystem decline), thus directly affecting processes such as succession, regeneration and mineral cycling. Furthermore, the altered ecosystem state may result in a system that is unhealthy, has lower diversity and having reduced fecundity of native species. In a few instances, early detection and eradication efforts have been successful at either eliminating the potential invasive species or containing it. The Asian gypsy moth that was introduces into the Pacific Northwest several years ago has not spread to the susceptible forests of the eastern U.S. and the Asian longhorn beetle outbreaks have been largely contained. Such successes are generally dependent on early detection and quick action.

Significance/Justification**:** Native plants and animals, that make up a particular ecosystem have co-evolved over millions of years, therefore native ecosystems have developed a state of dynamic equilibrium. The introduction of non-native species into a system can upset this balance when introduced species become “invasive”. National parks are especially vulnerable to species invasion because of the large number of visitors who enter the parks and serve as potential vectors of invasive organisms. At the forest community level, resources such as light, mineral nutrients and water are affected when invasive species either displace or attack and kill native species. Invasive organisms can bring about alterations in species composition, bio-productivity, regeneration and nutrient cycling, changing the diversity, vigor and fecundity of the ecosystem. The direct effects of an invasion include species displacement, infestation, and mortality of host species, but indirect effects such as shifts in species composition, altered nutrient cycling, modified temperature and light regimes often have more profound impacts than the direct effects (Kizinski et.al. 2002). The introduction of organisms has resulted in greater and more lasting ecosystem damage than virtually anything brought about by humans in recent history (Pimentel et. al 2000). In a few instances, early detection and eradication efforts have been successful at either eliminating the potential invasive species or containing it. A system of early detection of invasive species in National Parks would provide managers with a valuable management tool for coping with these pests.

***Proposed Metrics*:** In situations where an invading organism has not yet fully colonized a suitable habitat, the metrics chosen to describe the colonization is usually the area of colonization and the rate of advancement of the infestation or killing front. In the case where a non-invasive form of an organism precedes the invasive or reproductive stage (such as is the case when male gypsy moths precede the flightless female into an non-infested area), the presence and numbers of male moths can serve as an indication of the potential for invasion by reproductive populations. The impact of an insect or disease can be assessed within an infested zone by measuring the number or proportion of hosts that are colonized or killed (Morin et. al. 2005).

***Prospective Method(s) and Frequency of Measurement*:** Surveys of newly-introduced organisms that are potentially damaging to forest ecosystems are conducted by federal agencies such as the USDA Forest Service and the Animal and Plant Health Inspection Service (APHIS) as well as by state agencies such as the West Virginia Department of Agriculture, Plant Industries Division. Before developing an in-house program, the NPS should carefully review the programs that are already underway to determine whether or not they meet their needs. Once it is determined that a need exists for additional on-site surveys for an invading organism, the appropriate sampling scheme should be tailored to the specific situation. Early detection implies that detection of low-level populations will be possible. By definition, with “low level” populations the subject organisms are rare, therefore difficult to detect. Such detection systems are usually expensive and subject to error.

***Limitations of Data and Monitoring*:** The greatest limitation for early detection of invasive organisms is developing a cost-effective monitoring system that is statistically robust (Blossey 1999). The ERMN parks occupy extensive areas of land and some are situated in areas with large and remote forested components. Organisms can quickly spread from non-system lands onto parks, often vectored by park visitors. Invasive organisms can persist below detection levels and rapidly explode into outbreaks when favorable conditions occur. Data collected only on NPS lands will be of limited value in predicting the ambient population levels and therefore may not be useful in preventing spread of organisms from adjacent ownerships. It incumbent upon the NPS to choose carefully which organisms to focus on, concentrating on those most likely to do significant damage to the parks and to utilize data collected by other agencies, whenever possible.

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***Related Environmental Issues and Linked Vital Signs*:** Species invasion could be linked with Air and Climate (VS1-4), such that an altered climatic regime may predispose a site to being invaded. Invasive species may displace plants and/or animals from unique natural communities, and this is especially true for T&E species (VS49, 50), which may be living close to the limits of their existence in the absence of aggressive competitors. If invasive organisms alter the ecosystem, one result may be altered bioproductivity and nutrient cycling (VS61).

***Overall Assessment*:** Invasive species- early detection includes the detection of both exotic invasive species that displace natural species or communities as well as insects and diseases that injure or kill native species. Early detection is generally difficult because the organisms of interest are rare. However, these agents are potentially some of the most damaging of those affecting current terrestrial ecosystems. Their spread is often directly related to human activities, either deliberate, accidental or unintentional. This makes them all the more significant in National Parks where the human visitation rate is high. Surveys of invasive organisms, and those that are potentially invasive or damaging are routinely conducted by several federal and state agencies within the ERMN region and data from these surveys is public domain, therefore inexpensive or free to acquire (USDA, Forest Service 1993). But for certain key species, the NPS may wish to develop their own on-site survey data. The decisions regarding which species and how to sample for them should be weighed carefully, since valid early-detection surveys may be difficult, expensive and time consuming.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Forest Plant Communities – Structure and Dynamics (VS20)

***Brief Description*:** "Forest Plant Communities – Structure and Dynamics" deals with plants occupying all strata within stands (canopy, mid-story, understory) and it is specific to the stages of succession and stand dynamics (regeneration, stem exclusion, understory reinitiation, old-growth) that characterize the various communities within the ERMN parks. Owing to the successional stage, disturbance history and the site it occupies, there are certain parameters within which a community can be described as healthy. By measuring the structural and demographic features of a given community, an assessment can be made as to whether or not the ecosystem's parameters fall within expected norms. If not, it should raise concerns on the part of park managers to determine why the community is in an unhealthy state and would trigger actions to remediate and restore the community to a healthy state. Thus, structure and demography serve as indicators of ecosystem health.

***Significance/Justification*:** Determining ecosystem health, as with any diagnostic activity, requires knowledge about key processes. This knowledge serves a function similar to that of diagnostic testing in medical science. Ecologists utilize standard descriptors to characterize the structure and demography of ecosystems or communities depending on the stages of development of the ecosystem, such as regeneration, stem exclusion, understory reinitiation and old-growth. At each stage, it is important to document the parameters that describe the health of the ecosystem so that managers can determine which communities require attention and they can assign priorities for remedial work. Ecosystem health affects processes such as bio-productivity, regeneration, succession, and nutrient cycling.

***Proposed Metrics*:** The standard measures of demography include classification of forest communities into stages of development (regeneration, stem exclusion, understory reinitiation, old growth). These stages are somewhat subjective, therefore classification is interpretive. Measures of structure include stratification of crowns into dominant, codominant, intermediate and overtopped classes. Measures of stocking include basal stocking (e.g. square meters per hectare), number of trees per unit area and percent stocking relative to some fully stocked norm. Measures such as importance values are also used to characterize the structure of a forest community. Understories are often described in terms of area coverage by non-woody species and numbers per unit area for woody species (trees, shrubs, etc.). Tree seedlings in the understory are usually categorized by shade tolerance and size classes, both of which have a strong bearing on their future success. Species diversity as also a measure of the state of a community and standard measures of diversity include species richness, Shannon-Weiner H' and Simpson's Index.

***Prospective Method(s) and Frequency of Measurement*:** An "ecological inventory" will be required to acquire data needed to assess the demographics and structure of ecosystems. These inventories should involve permanent sample plots and these should be revisited at regular intervals (e.g. annually). Sampling should be stratified by the types of ecosystems (stages of development, etc.) present in each park. The size and needed number of such plots will depend on the size, density and variability of the organisms and/or populations being sampled, as well as the degree of accuracy desired. Smaller plots, in the range of 3- 4 m^2, that may be useful for sampling understory and regeneration, will not be suitable for overstory sampling. Hence, much larger plots would be necessary to characterize the tree strata. Data collected in an ecological inventory should be those that can be used to compute the standard ecological parameters, including tree species, dbh, total height, assessment of vigor, site conditions, understory coverage and species and density of regeneration. Healthy ecosystems are dynamic, therefore changes are to be expected. However, when the rate and nature of change deviates from the expected norm it may be a cause for concern to park managers. For example, when a certain species that was abundant in previous inventories begins to drop out at a more rapid rate than expected, or when regeneration is failing to ascend beyond the seedling stage it would be a cause for concern. Sources of data such as the USDA Forest Service, Forest Inventory and Analysis (FIA), can provide a background to compare with ecological inventory data, but since the FIA data do not directly address many ecological issues, the ERMN will most likely find it necessary to establish their own data base.

***Limitations of Data and Monitoring*:** In order to establish a reliable network of permanent samples, it will require considerable effort and expense. Furthermore, in order for the data to have any real utility, it will require long-term commitment to the remeasurement of plots and the analysis and interpretation of data.

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***Related Environmental Issues and Linked Vital Signs*:** The structure and demography of terrestrial communities is related to almost all the vital signs under the heading of “Biological Integrity” (VS18- VS50). Also, all the vital signs under the heading of “Ecosystem Pattern and Process” (VS57- VS61) are associated with plant community structure and demography. There are numerous interconnections and feedback relationships among these biological resource groups. For example, forest structure and demography directly affects breeding bird communities, and birds also affect forests as vectors of seeds, insects and fungal spores. Birds are also consumers of insects, and as such, they may be beneficial to infested plants.

***Overall Assessment*:** Ecosystems respond to their environment, and plants communities, are generally dictated by the environment within which they grow. Many species of plants are said to be “site specific” such as ginseng, which is often associated with the most productive sites or mountain laurel which generally occurs on lower quality sites. Plant populations also change their environment and as the environment changes, new species become more adapted, hence the process of succession. As primary producers, plant communities supply energy for all trophic levels above them, and are the key element in supplying niches for other species that inhabit the community. The structure of a plant community, apart from its energy relations, also contributes to habitat by supplying such things as nesting sites, escape cover and vocalization sites for birds. Because of the importance of plant communities’ structure and demography to the ecological health of ERMN parks, these are attributes which should be closely monitored. Normal (successional) ecosystem changes are expected to occur, but when ecosystems are changing in ways that do not conform to expected norms for healthy ecosystems, it is important for park managers to be aware of this, enabling them to respond appropriately.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Breeding Bird Community (VS32)

Brief Description**:** The “breeding bird community” refers to resident or neotropical migrant species of avifauna in the ERMN parks. Most of the species of importance in the ERMN system are forest-dwelling species, although some species that prefer open habitats may actually be relatively rare in the ERMN. Breeding birds are especially sensitive to habitat features such as canopy structure, nesting sites, food supplies and escape cover (Conner and Dickson 1997). Some species of birds, such as woodpeckers, may serve as indicators of overall bird diversity (Mikusinski, Gromadzki and Chylarecki 2001). Birds have been shown to be useful indicators of ecosystem health, and this is especially true where ecosystems are heavily impacted (Bradford et. al. 1998; O’Connell, Jackson and Brooks 2001). Declining abundance and diversity of sensitive bird species should be of concern to park managers since birds indicate overall ecosystem health and they are a resource that is sought after and appreciated by many park visitors.

Significance/Justification**:** It is clear that populations of breeding birds are associated with their habitat, which may in turn reflect the health of the ecosystem. For example, in the Savannah River of South Carolina (SRS), Kilgo et. al. (2000) found that bird species that preferred urban and agricultural habitats were more abundant off the SRS, while forest-interior species such as the cerulean warbler were more abundant within the relatively undisturbed SRS. One advantage of using breeding birds as indicators of ecosystem health is the fact that historical data exist regarding their populations. One example is the North American Breeding Bird Survey (Sauer et. al. 2000); and more specific to the ERMN is a survey reported by Yahner et. al. (2001) that was taken in six Pennsylvania National Parks, including the Allegheny Portage Railroad National Historic Site and the Johnstown Flood National Memorial. These surveys can serve as a baseline for assessing future trends on breeding bird populations. Finally, bird populations are important assets of National Parks, and to the extent that the ERMN parks contain unique habitat, they will also contain populations of birds that visitors will be drawn to.

Proposed Metrics: Metrics such as relative abundance of particular species (Bradford et. al. 1998) or guilds (Jones et. el. 2000) as well as overall species richness for species or guilds appear to be the most common means of assessing bird populations. These measurements are meaningful when tracked over time.

Prospective Method(s) and Frequency of Measurement**:** Bird presence and density are usually established by counts and/or reports from trained observers. These take the form of singing male surveys, counts of birds in migrating flocks, nesting surveys, bird banding/recovery studies and mist netting, or combinations of these. The particular method selected depends on the species to be inventoried. These inventories should be compared to historic baselines and previous inventories for the same areas. Therefore, the same areas should be sampled annually using the same methods (Beard, Scott and Adomson 1999). Sampling should be stratified proportional to the types of ecosystems (stages of succession, cover type, etc.) present in each park. The initial inventory, and/or historical surveys, will serve as a baseline, and subsequent samples will be used to determine if bird populations are changing over time. It will be important to select key species to concentrate on since it will be impossible to adequately sample all bird species present. These would be species that respond to desired ecosystem conditions and species that can be reliably inventoried. Since forest habitats may be transitioning through various successional stages, changes in bird populations would be expected to reflect habitat changes. However, if bird populations are changing to a non-desirable state (e.g. dominance by one or a few species, loss of critical species, rapid colonization by exotic species, etc.), it will be a cause for concern.

***Limitations of Data and Monitoring*:** Bird sampling requires that trained observers be available in order to maintain consistency. In addition, studies of this nature require long-term commitment, therefore are expensive to conduct. Analysis and statistical inferences from bird survey data are often limited by the inability to take large samples and the low number of observations that characterize rare, but important, species.

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***Related Environmental Issues and Linked Vital Signs*:** National parks are often islands that have been engulfed in a sea of private land. Activities that are on-going on adjacent land (timbering, surface mining, urban development, farming, etc.) can have a profound effect on the national park, and this is especially true regarding impact on bird populations. Breeding bird populations are also strongly linked to plant community structure and demography (VS20), which in turn can be affected by invasive plants, insects and diseases (VS18) and white-tailed deer (VS38).

***Overall Assessment*:** Birds are a resource that is important to visitors of ERMN parks, and breeding bird populations are very sensitive to their habitat (quality, structure, etc.). Considerable historic data exist on breeding bird populations, some of which is specific to particular ERMN parks, but several parks lack site-specific data. An annual monitoring scheme is recommended that will allow for tracking changes in density of critical species and guilds, as well as to observe overall species richness. Because bird inventories are difficult, require trained observers and must be maintained annually, a major commitment of personnel and funds will be required by the ERMN.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Terrestrial Invertebrates (VS34)

***Brief Description*:** The vital sign dealing with "terrestrial invertebrates" has to do with species of micro- and macro-invertebrates in the ERMN parks. These species include a variety of insects, arachnids and other species. A large number of invertebrate species are involved in the processes of litter and woody debris breakdown. Others consume living plant biomass (defoliators, sap feeders, seed insects, wood and bark borers, etc.) and others are involved in processes such as pollination, spore dissemination and seed dispersal. Diversity and abundance of invertebrates to a large extent reflects the diversity and health of host species and food sources, therefore these species serve as indirect indicators of ecosystem health (Kermen et. al. 1993; Taylor and Doran 2001). Certain species may serve a role as especially good indicators of overall ecosystem health and diversity. These include ground beetles (Rainio and Niemela 2003) and tiger beetles (Pearson and Cassola 1992). Changes in abundance and diversity of sensitive invertebrate species should serve as an index to changes in overall ecosystem states and therefore will serve to alert park managers to these changing conditions.

***Significance/Justification*:** Terrestrial invertebrates, by far, represent the most numerous and diverse taxa in forest ecosystems. Not only do they serve as indicators of ecosystem condition, but many species perform vital ecosystem functions such as shredding of leaf litter, pollination, seed dispersal, soil aeration, etc, while others serve as food sources for organisms at higher tropic levels. Diversity of species like butterflies also can also serve as indicators of ecosystem changes, such as global warming and rainfall patterns (Pollard 1998). Because of their diversity and ubiquitous occurrence, terrestrial invertebrates are very important functional components of terrestrial ecosystems and useful indicators of ecosystem health.

Proposed Metrics: Because of the great diversity and richness of terrestrial invertebrates, from a practical viewpoint it is useful to focus on *indicator taxa*. Kerr, Sugar and Packer (2000) found that species of Lepidoptera were suited to this purpose in oak savannahs in Ontario. As a refinement to this approach, Oliver and Beattie (1996) suggested combining the use of indicator taxa with the identification of appropriate sampling schemes (timing, methods) to maximize the information gained while minimizing the effort required for inventories. The appropriate metrics are measures of diversity (richness, evenness, etc.), density and importance and these measurements should be tracked over time and/or compared with existing baseline data.

***Prospective Method(s) and Frequency of Measurement*:** Initially, decisions will need to be made to determine which taxa of terrestrial invertebrates will be focused on. This decision will depend on which ones are good "indicator taxa" and/or are functionally important to the parks. Once this decision is made, an initial inventory should be conducted to determine the density, distribution and diversity of the selected taxa in the ERMN parks in order to establish a baseline. Sampling should be stratified proportional to the types of ecosystems (stages of succession, cover type, etc.) present in each park. Future monitoring (probably on a yearly or biennial basis) will be used to determine if populations are changing over time. Using the "indicator taxa" approach should allow the manager to extrapolate to other organisms and to use the data to assess overall ecosystem health. Since forest ecosystems are dynamic, it is reasonable to expect different populations of invertebrates in different ecosystems

***Limitations of Data and Monitoring*:** Perhaps the sheer diversity, discontinuity and density of invertebrate populations are limitations in and of themselves. Thoroughly sampling these populations is a difficult task and, if sampling of all species present is necessary, it would be virtually impossible, and very expensive.

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***Related Environmental Issues and Linked Vital Signs*:** Because of their great numbers and diversity, terrestrial invertebrates have a profound effect on many aspects of the ecosystem. Their populations may be affected by atmospheric pollution (VS1, VS2) or they may interact with such things as weather and climate (VS4). Even soil properties such as compaction (VS11) can be ameliorated by the presence of some terrestrial invertebrates. The leaf shredder populations are very much a function of the type of litter produced (Mudrick et. al 1994), which in turn is a function of the overstory community present (VS20). Litter decomposition and nutrient cycling (VS60, VS61) are affected by shredder populations and these, in turn affect bio-productivity (VS59). A number of invertebrates function in ways that affect the overall ecosystem function. For example invasive insects (VS18) like gypsy moth pose a significant threat to ecosystem health in the ERMN. Many other invertebrates are contributory to ecosystem health, such as pollinators, earthworms, etc.

***Overall Assessment*:** Terrestrial invertebrates are very diverse and important to the functioning of the ecosystems in the ERMN. Some, like introduced insect pests are detrimental as well. Monitoring the overall diversity and the populations of selected invertebrate species should yield information that is valuable to park managers. In order to expedite the process, it will be necessary to monitor “indicator taxa” and a stratified sampling scheme should be devised that will monitor invertebrates in the various forest cover types and successional stages present. Once a baseline has been established, monitoring on an annual or biennial frequency should provide managers with a perspective on the maintenance of diversity among invertebrates in the parks, which should serve as an indicator of ecosystem health.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Reptiles and Amphibians (VS48)

***Brief Description*:** "Reptiles and amphibians" refer to the populations of herptofauna occurring in the ERMN parks. Species of reptiles and amphibians of interest include frogs, toads, turtles, terrapins, salamanders, lizards and snakes. Herptofauna, especially frogs and salamanders have been reported to be in decline worldwide and have been identified as indicators of ecosystem stress (Welsh and Oliver 1998). In part, this derives from the fact that the exothermic herps are intimately dependent upon their environment for heat and food; even to the extent of absorbing water and gases through their skin. Certain species (notably snakes and lizards) seem to prefer open and dry habitats, while salamanders and frogs prefer moist habitats (Crosswhite, Fox and Thill 2004). Impacts of global climate change, atmospheric deposition and air pollution would most likely be apparent in herptofaunal communities before they would in other sectors of the terrestrial ecosystem. Therefore, the health and diversity of herptofauna in ERMN parks should be monitored closely in order to provide indications of ecosystem changes.

***Significance/Justification*:** Herptofauna are relatively diverse in the ERMN region, being represented by 35- 50 species (Green and Pauley 1987, Kilpatrick et. al. 2004). Because of their environmental sensitivity, these species represent potentially good indicators of ecosystem health. Although not specific to the individual ERMN parks, there exists a comprehensive compilation of data regarding herptofauna in the eastern deciduous and Appalachian forest regions (Pauley 2001) which can serve as a historic background for comparison with present and future populations.

Proposed Metrics: Relative density and diversity (richness) are the commonly-used measures to describe herptofauna in forested ecosystems. For relative density, number of a particular species compared to the total number of all species is the metric of choice. Because of the difficulty of sampling, it may be hard to find certain herp species, especially at times of the year when they are inactive or hibernating, so sampling should focus on areas of prime habitat and should be conducted at times when target species are active.

***Prospective Method(s) and Frequency of Measurement*:** There are a variety of sampling methods used to collect and inventory herptofauna (Corn and Bury 1990). For snakes and terrapins, drift fences, leading to pitfalls or double-ended funnels are frequently used. Frogs, newts and toads can be trapped with funnel traps, either in aquatic or terrestrial habitat; again, the trapping method should conform to the target species, and the activity phase they are in at a given time since many species of amphibians have both terrestrial and aquatic phases. Salamanders are usually inventoried using coverboards (Felix, Wang and Schweitzer 2004), and here again, sampling should be conducted at times of the year when salamanders are active, and not during periods of extended dry weather or extended wet weather. Herptofauna sampling should be stratified by broad forest cover types (conifer, oak forests, northern hardwoods, mesophytic hardwoods), and stages of ecosystem development (recently-disturbed, second-growth, old-growth). Since there are several species of herptofauna to inventory, it may be difficult, time-consuming and expensive to attempt to inventory them all each year. Using a staggered schedule over a period of 3- 5 years the ERMN could monitor part of the species each year. In so doing, annual inventories can be conducted for species having similar habits, therefore those that can be inventoried using the same, or similar, methods. At the end of a full cycle, the first species group inventoried would be re-sampled and over a period of several cycles, trends in relative density of individual species and overall diversity can be established.

Limitations of Data and Monitoring: Most species of herptofauna are small in size and active only during part of the year in temperate forests. Some live in the soil or beneath leaf litter or rocks, therefore sampling must be done in ways that accumulate them (drift fences, coverboards, etc.), so exact population numbers are difficult to obtain, since it is impossible to obtain a census of all individuals in a particular land area. This is one reason herpetologists often rely on relative density and diversity when describing the herptofaunal community of an area. In the case of threatened and endangered species, such as the Cheat Mountain salamander, the fact that they are rare, complicates sampling and makes it necessary to concentrate sampling efforts in areas of prime habitat, which may in itself pose a threat to the species.

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Related Environmental Issues and Linked Vital Signs**:** Herptofauna, because of their proximity to the soil and dependence on ambient moisture and temperature are very sensitive to climatic effects (VS1- VS5), In addition, soil and geologic conditions (parent material, soil texture, stone content, compaction, etc. have a profound effect of herptofauna (VS11, VS12). The overstory community also has an important effect on herptofauna, since many species live in the organic soil layers which are produced from decomposing organic matter produced by the trees (VS20). Terrestrial invertebrates (VS 34) constitute a major food source for many herps (VS34), and some herptofauna are among the state and federal T&E species (VS49, VS50). Finally, herptofauna are particularly susceptible to damage from visitor over-usage (VS54), and because of their limited mobility herptofauna may be especially sensitive to changes in the land cover or land use (VS57). Herptofauna , because of their sensitivity, diversity and links to many other vital signs make good indicators of ecosystem health and stability.

***Overall Assessment*:** Herptofauna represent a diverse group of organisms that have experienced world-wide declines in recent decades. They are generally acknowledged to be sensitive to changes in their environment, including climate change as well as atmospheric pollution. These species could provide ERMN park managers with an early warning system for ecological degradation. Because of their life histories and habitat characteristics, herptofauna are difficult to survey and monitor, but a well-planned system of sampling should provide good data for establishing trends in relative densities and diversity, which should, in turn, be a valuable descriptor for use by park managers.

Level 1 ► Biological Integrity
Level 2 ► At Risk Biota
Level 3 ► At Risk Biota, Federal and State and Special Concern (VS49 & VS50)

***Brief Description*:** "At-risk species and communities" refers to state or federally listed species (either threatened or endangered) as well as other species or communities that are either rare or imperiled occurring in the ERMN parks. For federally listed species, the NPS is mandated to protect them and to report on the status of their populations. Because of their T&E status, many of these species may be relatively sensitive to alterations in the ecosystem, and as such serve as "early warning" signals for environmental problems that may have more sweeping effects over time. Within the ERMN, there are federally listed plants (Virginia spirea), aquatic species (dwarf wedgemussel), herps (bog turtle) and mammals (Virginia big-eared bat). These species could serve as **indicators** of ecosystem stress (Welsh and Oliver 1998). Impacts of global climate change, atmospheric deposition and air pollution would most likely be apparent in T&E species before they would in other sectors of the terrestrial ecosystem (Hansen 2001).

***Significance/Justification*:** Rare species are large contributors to biodiversity, especially when species richness is used as a measure of diversity (Cao et al, 1998), therefore it is important to monitor them and to take remedial action when their populations decline (Brussard et al 1992). Many T&E species have specializes habitat requirements (Castleberry et al 2001) and they may require specialized food sources; e.g. Virginia big-eared bats selectively consumed Lepidoptera larvae in West Virginia (Sample and Whitmore 1993). As indicators of overall ecosystem health, at-risk species provide an early warning mechanism.

***Proposed Metrics*:** Relative density and diversity (richness/evenness) are the commonly-used measures to describe at-risk species in terrestrial ecosystems. For rare species, especially perennial plants, it may be possible to count all of them at particular locations and if sampling is conducted over time, to document whether or not the numbers are increasing, decreasing or remaining static. In some instances, again with regard to plant populations, the area of coverage by the species may be more meaningful than the absolute number. Because they are, by definition, rare, it may be difficult to find certain species, especially at times of the year when they are inactive, dormant or hibernating, so sampling should focus on areas of prime habitat and should be conducted at times when target species are active.

***Prospective Method(s) and Frequency of Measurement*:** There are a variety of sampling methods used to collect and inventory rare species (Corn and Bury 1990). Sampling methods and frequency will vary according to the species being monitored. For plant species, standard plant population sampling methods (usually fixed-area plots or transects) provide the best results. For animals, counts, habitat analysis, and live trap-recapture methods are some of the methods used. Because the species are, by definition, “at-risk”, it is imperative that the sampling methods be low-impact and not be contributory to the decline of the target organism. Generally, inventories of T&E species will be difficult, time-consuming and expensive, but in some cases they will be mandated. For state-listed species and others that are not federally listed, the ERMN should direct their sampling efforts to species that are likely to provide the most useful information for the funds expended.

Limitations of Data and Monitoring**:** The greatest limitation regarding monitoring at-risk species is the magnitude of the task. If all state and federally listed species are targeted, the ERMN will have to monitor a wide array of life forms and a large number of species. The resources, expertise and personnel required to accomplish such a task is staggering and will probably be impossible on a limited budget.

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Related Environmental Issues and Linked Vital Signs: At-risk species and communities because of their sensitivity to environmental stresses are sensitive to climatic effects (VS1- VS5), In addition, soil and geologic conditions (parent material, soil texture, stone content, compaction, etc. have a profound effect of plants and animals in a particular habitat (VS11, VS12). Finally, at-risk species and communities are particularly susceptible to damage from visitor over-usage (VS54), and may be especially sensitive to changes in the land cover or land use (VS57).

Overall Assessment**:** At-risk species and communities represent a diverse group of organisms that, by definition are experiencing declining numbers. They are generally acknowledged to be sensitive to changes in their environment, including climate change as well as atmospheric pollution. These species could provide ERMN park managers with an early warning system for ecological degradation. Because of their diverse life histories and habitat characteristics, at-risk species are difficult to survey and monitor, but a focused system of sampling should provide useful data for establishing trends in relative densities and diversity, which should, in turn, be a valuable descriptor for use by park managers.

Level 1 ► Human Use
Level 2 ► Visitor and Recreation Use
Level 3 ► Visitor Use (VS54)

Brief Description**:** "Visitor use" refers to the impact on ERMN parks that is caused by human usage, including direct impacts such as soil compaction and devegetation as well as indirect effects such as pollution caused by auto emissions and human waste. Because of the federal mandate to National Parks to preserve unique resources and natural areas for the benefit of the American people, a paradox exists such that over-use runs the risk of destroying the very resources that people come to use. Parks in the ERMN area are generally within a day's drive of more than 50% of Americans, therefore they are heavily used by visitors and this usage will likely increase in the future. Activities such as rock climbing are especially prone to do damage since cliffline areas are a relatively rare component of the landscape and the types of flora and fauna associated with them is often unique to these rare sites (McMillan and Larson 2002; Eagles 2001; Kelly and Larson 1997). Trails concentrate the impact of users (which can mitigate the general impact of dispersed use), but trails must be well planned, appropriately located, regulated as to type and amount of use and well maintained in order to prevent excessive damage (Weaver and Dale 1978). The dilemma presented to park managers is to determine how to preserve the valuable resources in national parks while at the same time making them available to the public.

Significance/Justification**:** Using Manion's (1981) classification of ecosystem stressors, visitor usage would fall into the category of a contributing factor. The ecological impact of visitors depends very much on the number and type of visitors, the sensitivity of the resource(s) being affected, and the overall environmental context. For example, a large number of visitors riding ATV's in a wetland site would have a much higher impact than the same number of birders visiting an upland forest site on foot. But even activities that would appear benign at first glance may cause damage, especially when they occur repeatedly over the long term. It is important for the ERMN park managers to assess the short-term and long-term impacts of visitors and to manage these impacts in order to minimize ecosystem damage.

Proposed Metrics**:** Determining visitor impacts is a difficult task, especially when there is little opportunity to develop controlled experiments. For example, the impact of white-water activities on the flat-rock communities of the New and Gauley Rivers may be difficult to ascertain, since there is no suitable experimental control. Indeed, even if pre-post information existed, it would be of limited value since other things are probably changing in the environment over any given interval of time. Cessford and Muhar (2004) describe the range of options available for visitor monitoring in National Parks, but simply documenting the numbers and attributes of visitors may not adequately address the type and level of damage they are causing. In many cases, inventories of sensitive plants and animals in high-use areas will be a required component of any visitor-impact monitoring program in order to link visitor usage with environmental damage. Thus metrics such as visitor person-days will need to be associated with ecosystem metrics such as relative density and diversity of sensitive plant and animal species in order to see the complete picture.

***Prospective Method(s) and Frequency of Measurement*:** In order to establish the resource impacts that occur as a result of visitor usage, controlled experiments are the best option using several replications of "test" sites that are experiencing high visitor pressure and a similar set of "control" sites which are receiving little or no impact over the same interval. In order for such and experiment to be valid, the two sets of sites should be as similar as possible, and having a similar history of disturbance prior to the initiation of the experiment. Such an experiment is seldom practical since the "test" areas are probably sites that have had historically high visitation rates, since they possess unique and interesting attributes (e. g. a scenic viewing areas or waterfalls). A practical alternative is the use of so-called before-after-control-impact-pair (BACIP) designs (Stewart-Oaten and Murdoch 1986). In these studies, control and test areas are monitored prior to the impact for several years and then again following the initiation of visitor impact. This is especially suitable where a new facility is being constructed in an area that has here-to-fore been relatively unaffected by visitors. Another method of establishing impact, that is especially suited to sites where visitor use is concentrated, is the installation of transects radiating away from the high-use area. This is especially suited to campsites, trails, picnic areas, etc. The variables to monitor for impact in any of these studies would be those suspected to receive either direct or indirect impact (species diversity, soil compaction, presence or absence of sensitive species, etc.). At such time as an impact is apparent, the park manager may wish to establish limits on the number and/or timing of permitted visits. Wang and Manning (1999) describe a modeling tool that could be used to set "carrying-capacity" limitations on park usage which may be a reasonable approach to managing visitor impacts.

Limitations of Data and Monitoring: As indicated above, there is an almost endless combination of types of resources/ecosystems, types of visitor impacts and sensitivities of ecosystem components, so any viable monitoring system for visitor impacts should be focused on sites where impacts are most likely to occur. Many of the standard experimental designs and sampling methods are of limited value in developing visitor impact data, so methods like the BACIP design are required. These methods may not be as robust as statistical designs where strict control over the experimental conditions is possible. Finally, because of the difficulty in acquiring data and the number of potential ecosystem impacts, visitor impact analysis can be expensive and time consuming.

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Related Environmental Issues and Linked Vital Signs**: Visitor** impacts are especially significant regarding soil compaction/erosion (VS11), which, in turn, can affect soil biota (VS12) and terrestrial invertebrates (VS34). Visitors are likely to have impacts on certain unique resources such as rimrock pine communities, clifflines and cliffline communities (VS21, VS8, VS22), which, in turn, can affect cliff-dwelling species such as peregrine falcons, Allegheny woodrats (VS35) and bats (VS33). Visitors also can create noise pollution (VS55) as well as initiate changes in land use patterns, bio-productivity, litter dynamics and nutrient cycling (VS 57, 58, 59, 60, 61).

***Overall Assessment*:** Because national parks are sites set aside for the use and enjoyment of the public, a paradox exists between preserving the resources and allowing people to use them. Therefore, park managers must walk a tightrope between permitting use and preserving the environment. Visitors to parks have the potential of causing widespread damage, including destruction of habitat, local loss of species and soil compaction and erosion. The park managers need data to determine the extent of visitor damage and to enable them to set carrying-capacity limits in areas where use threatens important resources. Methods for assessing visitor use and visitor impacts are often difficult and expensive to apply and should be targeted to sensitive resources in high-use areas.

Level 1 ► Landscapes (Ecosystem Pattern and Process)
Level 2 ► Landscape Dynamics
Level 3 ► (VS57) Land Cover and Use

Brief Description**:** "Land cover/land use change" refers to the dynamic and changing state of land uses that are taking place on the landscape mosaic. It is particularly relevant to the anthropogenic changes that are occurring outside the parks, such as urban and industrial development, timber harvesting, mining, etc. As a benchmark to the current pattern, historic patterns (Braun 1950) should be considered, as well as trends and changes in landscape patterns. These changes can be useful indicators of the natural and human-caused forces acting upon the landscape (Alig and Butler 2004). Turner et. al. (2003) examined the landscape-level changes in the Appalachian region (including much of the ERMN) and found that during the four-decade interval from 1950 to 1990, the amount of forest cover increased and fragmentation decreased, but they cautioned that recent housing development in the region may offset many of these gains. Human impacts are a critical element in the changing landscapes of the ERMN and Ritters et. al. (2000) observe that land cover information provides a mechanism to place humans into the process of ecological assessment. The science of landscape ecology represents an emerging discipline that utilizes technology (GPS, GIS) to study spatial patterns on the landscape. This vital sign is an attempt to observe the temporal changes that take place over the landscape and relate these to factors that affect the vitality of ERMN parks.

Significance/Justification**:** Humans are one of the primary drivers in landscape-level changes (Ritters et. al. 2000). Historical occurrences such as agricultural clearing, agricultural abandonment, timbering, surface mining, forest fire control, predator eradication, hunting regulation, insect and disease introductions and urban sprawl are all examples of how humans have contributed to landscape-level changes over the last hundred and fifty years. ERMN parks are in-effect islands within an ever-changing mosaic of land, and changes outside the ERMN parks can potentially affect the ecological properties within the parks (Brosofske et. al. 1999). Roads have a particularly profound fragmenting effect on terrestrial ecosystems (Forman 2000; Trombulak and Fressell 2004). Changes in landscape pattern can alter habitat for neotropical birds, mammals (Dijak and Thompson 2000) and forest wetlands (Gibbs 2000). Because land use patterns surrounding the ERMN are changing and these changes have the potential for altering the ecological characteristics within the parks, it is important that park managers be aware of this process and how it is likely to affect them.

Proposed Metrics**:** Landscape ecology is a field that uses spatial analysis methods to evaluate the pattern of various land cover types at different spatial scales. Metrics include the proportion of a given landscape occurring in a particular cover type and indices of patchiness, fragmentation, connectivity etc. These metrics can be used to compare among landscapes or to observe temporal changes in a single landscape. In addition to describing the landscape mosaic directly, it may be useful for ERMN parks to measure and correlate variables that are sensitive to changing landscape patterns. For example, Bosofske et al (1999) found a significant relationship between biodiversity as measured by the Shannon-Weiner index and overstory patch type.

***Prospective Method(s) and Frequency of Measurement*:** Spatial analysis methods begin with imagery (aerial photography, satellite images, etc.) and databases (USGS topographic information, ownership, etc.). Image information requires interpretation in order to determine what the visual information represents. Interpretation can be facilitated by image enhancing methods, such as digital color transformations. The resulting information is used to create a geographic information system (GIS) that incorporates multiple layers of spatial information, such as land use, ownership, cover type, topography, etc. Software packages are available that provide powerful tools for organizing, interpreting and displaying the information. Spatial statistics can be used to analyze the data (Gardner et. al. 1987), and models constructed using information from known landscapes can be used to predict the states of other landscapes (Baker 1989, Trombulak and Frissell 2004). The changes in landscape pattern can be documented by replicating landscape pattern studies over time.

***Limitations of Data and Monitoring*:** A substantial amount of landscape-level information currently exists, much of which is public record, and therefore inexpensive to acquire. The problem with many available sources of images or spatial data is that they must be adapted to the specific use required (e.g. ERMN parks). The detail, scale and type of imagery may not suit the specific purpose of the ERMN, requiring that new and expensive data need to be gathered. The development of a system-wide GIS can be a daunting task, requiring, either contractors or trained NPS employees to complete the work. Furthermore, as Li and Wu (2004) and Jones et al (2001) warn, landscape analysis often falls short of meeting its high expectations due to conceptual flaws in pattern analysis, inherent limitations of landscape indices and improper use of pattern indices.

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Related Environmental Issues and Linked Vital Signs: Land cover/land use change is related to many environmental issues, particularly ones having to do with anthropogenic effects, such as pollution, land use, settlement, etc. Landscape patterns are linked with almost all the vital signs identified for ERMN parks. Atmospheric and climatic patterns (VS1- VS4) vary across the landscape, and these factors, in turn, create patterns in vegetation and land use. Geology and soils (VS6- VS12) also contribute to landscape patterns, as well as do hydrologic features (VS14, VS15). Because human activities often are involved in the introduction of invasive species, and human habitation is part of the landscape pattern, the pattern of introduction of invasive species (VS18) often follows patterns of human activity (transportation, settlement, etc.). Plant and animal communities (VS20- VS48) are specifically adapted to their environment, and changes in their environment may result in their extirpation or decline. Visitor usage (VS54) can locally alter an ecosystem, therefore imposing an anthropogenic pattern on the landscape. In short, the pattern that exists on the landscape at a particular point in time is a reflection of the sum of the abiotic, biotic and anthropogenic factors that interact over it, and if that suite of factors is changing, park managers should be aware of the changes and their potential impacts on park resources.

Overall Assessment**:** Land cover/land use change is a function of many factors, both internal and external to the ERMN parks. Human activities such as development (roads, structures, timbering, mining, etc.) are primarily responsible for the landscape-level changes that are taking place outside the park boundaries. These activities could have profound effects on ERMN parks, but unfortunately are largely out of the control of park managers. The discipline of landscape ecology has been developed in recent years and involves using imagery, data, technology and statistical tools to analyze and interpret spatial information. ERMN managers can use these methods to assess changing land use patterns in and around their parks. Knowledge of the landscape-level changes that are taking place will enable managers to anticipate how these changes may affect their resources and to the extent possible, take remedial actions.

Level 1 ► Landscapes (Ecosystem Pattern and Process)
Level 2 ► Landscape Dynamics
Level 3 ► (VS58) Landscape Pattern

Brief Description**:** "Landscape Pattern" refers to the states and distribution of the various dominant cover types, as they exist within a landscape mosaic. In addition to the current pattern, historic patterns (Braun 1950) should be considered, as well as trends and changes in landscape patterns. These changes can be useful indicators of the natural and human-caused forces acting upon the landscape (Alig and Butler 2004). Turner et. al. (2003) examined the landscape-level changes in the Appalachian region (including much of the ERMN) and found that during the four-decade interval from 1950 to 1990, the amount of forest cover increased and fragmentation decreased, but they cautioned that recent housing development in the region may offset many of these gains. Human impacts are a critical element in the changing landscapes of the ERMN and Ritters et. al. (2000) indicate that land cover information provides a mechanism to place humans into ecological assessments.

Significance/Justification**:** Humans are one of the primary drivers in landscape-level changes (Ritters et. al. 2000). Historical occurrences such as agricultural clearing, agricultural abandonment, timbering, surface mining, forest fire control, predator eradication, hunting regulation, insect and disease introductions and urban sprawl are all examples of how humans have contributed to landscape-level changes over the last hundred and fifty years. ERMN parks are in-effect islands within an ever-changing mosaic of land, and changes outside the ERMN parks can potentially affect the ecological properties within the parks (Brosofske et. al. 1999). Roads have a particularly significant fragmenting effect on terrestrial ecosystems (Forman 2000; Trombulak and Fressell 2004). Changes in landscape pattern can alter habitat for neotropical birds, mammals (Dijak and Thompson 2000) and forest wetlands (Gibbs 2000). Because land use patterns surrounding the ERMN are changing and these changes have the potential for altering the ecological characteristics within the parks, it is important that park managers be aware of this process and how it is likely to affect them.

Proposed Metrics**:** Landscape ecology is a field that uses spatial analysis methods to evaluate the pattern of various land cover types at different spatial scales. Metrics include the proportion of a given landscape occurring in a particular cover type and indices of patchiness, fragmentation, connectivity etc. These metrics can be used to compare among landscapes or to observe temporal changes in a single landscape.

Prospective Method(s) and Frequency of Measurement**:** Spatial analysis methods begin with imagery (aerial photography, satellite images, etc.) and databases (USGS topographic information, ownership, etc.). Image information requires interpretation in order to determine what the visual information represents. Interpretation can be facilitated by image enhancing methods, such as digital color transformations. The resulting information is used to create a geographic information system (GIS) that incorporates multiple layers of spatial information, such as land use, ownership, cover type, topography, etc. Software packages are available that provide powerful tools for organizing, interpreting and displaying the information. Spatial statistics can be used to analyze the data (Gardner et. al. 1987), and models constructed using information from known landscapes can be used to predict the states of other landscapes (Trombulak and Frissell 2004).

***Limitations of Data and Monitoring*:** A substantial amount of landscape-level information currently exists, much of which is public record, and therefore inexpensive to acquire. The problem with many available sources of images or spatial data is that they must be adapted to the specific use required (e.g. ERMN parks). The detail, scale and type of imagery may not suit the specific purpose of the ERMN, requiring that new and expensive data need to be gathered. The development of a system-wide GIS can be a daunting task, requiring, either contractors or trained NPS employees to complete the work. Furthermore, as Li and Wu (2004) warn, landscape analysis often falls short of meeting its high expectations due to conceptual flaws in pattern analysis, inherent limitations of landscape indices and improper use of pattern indices.

***Key References*:**
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Wear, D.N. & Bolstad, P. 1998. Land-use changes in southern Appalachian landscapes: spatial analysis and forecast evaluation. Ecosystems, 1(6): 575-594.

***Related Environmental Issues and Linked Vital Signs*:** Landscape pattern is related to many environmental issues, particularly ones having to do with anthropogenic effects, such as pollution, land use, settlement, etc. Landscape patterns are linked with almost all the vital signs identified for ERMN parks. Atmospheric and climatic patterns (VS1- VS4) vary across the landscape, and these factors, in turn, create patterns in vegetation and land use. Geology and soils (VS6- VS12) also contribute to landscape patterns, as well as do hydrologic features (VS14, VS15). Because human activities often are involved in the introduction of invasive species, and human habitation is part of the landscape pattern, the pattern of introduction of invasive species (VS18) often the follows patterns of human activity (transportation, settlement, etc.). Plant and animal communities (VS 20- VS48) are specifically adapted to their environment, which changes across the landscape. Visitor usage (VS54) can locally alter an ecosystem, therefore imposing an anthropogenic pattern on the landscape. Finally, bio-productivity and nutrient dynamics (VS59, VS61) are specifically linked to the landscape pattern. In short, the pattern that exists on the landscape is a reflection of the sum of the abiotic, biotic and anthropogenic factors that interact over it.

***Overall Assessment*:** Landscape pattern is a result of the interaction of numerous factors (historic and present). ERMN parks are themselves part of a larger landscape, and are affected by actions that take place beyond their boundaries. The discipline of landscape ecology has been developing in recent years and involves using imagery, data, technology and statistical tools to analyze and interpret spatial information. ERMN managers can use these methods to assess current conditions in their parks as they relate to the larger landscape. Use of this tool may enable managers to anticipate changes and take remedial actions, when necessary.

Level 1 ► Ecosystem Pattern and Process
Level 2 ► Primary Production
Level 3 ► Primary Production/Biomass Production (VS59)

***Brief Description*:** "Primary Production/Biomass Production" relates to primary productivity of terrestrial ecosystems and the factors that influence it. Primary productivity is a function of the site quality (available resources), the stage of development of the ecosystem and the health of the ecosystem. Thus for a given level of site quality and stage of development, primary productivity can be used as an indicator of ecosystem health. Primary productivity is often measured in terms of gross primary productivity (GPP), or more commonly as net primary productivity (NPP) which accounts for losses due to mortality. Various methods or measuring and or modeling NPP have been developed. Some, such as Normalized Difference Vegetation Index and Enhanced Vegetation Index, use remotely-sensed data from satellite imagery (Weier and Herring, 2005). Others utilize data from USDA, Forest Service Forest Inventory and Analysis (FIA) plots (Wharton and Raile 1984). In the absence of directly measured biomass data, models have been developed that can be used to predict the amount of biomass present, given certain information on site and forest conditions (Botkin, Janak and Wallis 1972; Running andd Gower 1991). These biomass accumulation models provide a baseline against which actual biomass production of a given ecosystem can be compared.

***Significance/Justification*:** Primary production (NPP) is a fundamental property of ecosystems (Geiger at. Al. 2001). Biomass produced by autotrophs forms the foundation of the energy pyramid, and sets basic limits on all higher trophic levels. The "direct factors" (resources) that determine potential bio-productivity are solar radiation, heat, available water, oxygen, carbon dioxide and mineral nutrients (Hicks, 1998). At some point, one or the other of these resources becomes a limiting factor, and productivity of the ecosystem then becomes limited by the level of that resource. Ecosystems within landscapes have "expected norms" for productivity, therefore any deviation from this may indicate a change in some ecosystem property. Therefore tracking biomass production provides an important tool for ERMN park managers.

***Proposed Metrics*:** Metrics for reporting biomass productivity generally take the form of a rate, such as weight per unit area per unit time (Kg/ha/yr). In some case, surrogate variables can be measured to estimate productivity. For example, Ryan (1991) suggested using litterfall to estimate below-ground carbon allocation and tissue nitrogen content to estimate maintenance respiration.

***Prospective Method(s) and Frequency of Measurement*:** Ecosystem biomass components include living and dead fractions as well as above- and below-ground components. Obviously, the above-ground living component is the simplest to measure, while below-ground biomass (both living and dead) is very difficult to measure (Richter et.al.1999). Often, based on prior studies where total biomass has been measured, the relationship of below-ground to above-ground biomass is established and this relationship is used to predict below-ground amounts from above-ground measurements. Therefore, the method of monitoring involves the establishment of plots (often in the .05 ha size range) in which above-ground living biomass is measured. In actuality, biomass (dry weight) is seldom measured directly. Rather, biomass is estimated from easily measured attributes of the plants present (diameter, height, species, etc.). The above-ground component of dead biomass (leaf litter, dead wood, etc.) is also relatively measurable, but as with living biomass, the below-ground fraction of dead biomass is frequently estimated. Plots should be revisited on a five- to ten-year cycle in order to establish trends in biomass accumulation. An alternative to field measurements is to use remotely-sensed information to predict biomass. Satellite imagery has been used to develop the "Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). Such tools can be effective in differentiating between broad biomes (desert, savannah, deciduous forest, coniferous forest) and they are also effective at detecting large-scale drought stress within a biome. But at the level of the ERMN parks, they may be of limited value.

Limitations of Data and Monitoring: In order to monitor the state of biomass accumulation in a forested ecosystem, an extensive network of plots will be required. These will be expensive and difficult to install, furthermore, in order to track biomass trends, these plots will need to be monitored every five to ten years. This requires that permanent plots be put in place, and the same plots should be measured periodically, which presents problems such as relocating the plots. The limitations with regard to the difficulty of sampling components such as below-ground biomass have been described above, and this and similar sampling problems necessitates the use of estimated values for non-measurable components. Therefore, to the extent that these estimates deviate from the actual values, errors will be made.

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Related Environmental Issues and Linked Vital Signs**:** Primary productivity provides the energy that sustains all heterotrophic organisms in an ecosystem, and, given certain constraints, is an indicator of ecosystem health. Net Primary Production (NPP) is a function of the available resources and the stage of ecosystem development. NPP is linked to a wide array of other vital signs. For example, air pollutants (VS1, VS2) can reduce NPP, and weather, especially precipitation and temperature (VS4), can cause dramatic year-to-year fluctuations in NPP. Atmospheric enrichment with CO^2 can potentially increase biomass productivity by stimulating more rapid rates of photosynthesis (DeLucia and Thomas 2000). Geology and soils (VS11) are important in determining the productive potential of sites. Different forest plant communities (VS20) are inherently different in their productive potential, and anthropogenic impacts (VS54) can alter these communities, for example by the introduction of invasive species (VS18), or via soil compaction. A number of animal species depend, either directly or indirectly, on the biomass from NPP, including birds (VS29, VS32), riparian mammals (VS30) invertebrates (VS34), white-tailed deer (VS38) and reptiles and amphibians (VS48). Finally, primary productivity is very important in processes such as decomposition and nutrient dynamics (VS60, VS61).

Overall Assessment**:** Because primary production of an ecosystem is the foundation of its trophic structure and because it is linked to a variety of ecosystem attributes and functions, it is important to monitor trends in NPP in ERMN parks and to determine if biomass productivity is occurring within expected norms for healthy ecosystems. The field methodology for monitoring bio-productivity, however, is difficult and time consuming, especially with respect to below-ground components. But, because bio-productivity can affect many ecosystem properties, it may be worthwhile to monitor, if only on a relatively long-term measurement cycle (e.g. ten years).

Level 1 ► Ecosystem Pattern and Process
Level 2 ► Nutrient Dynamics
Level 3 ► Nutrient Dynamics (VS61)

***Brief Description*: **"Nutrient Dynamics" involves the cycling of mineral nutrients through the soil-plant-water system as well as the inputs (atmospheric, rock weathering) and outputs, (leaching, stream export, aerosols, harvesting). A number of mineral substances are required for plant growth and development. A partial list of these includes the so-called "major nutrients" (nitrogen, phosphorous, potassium, magnesium, calcium and sulphur) as well as the "minor nutrients" (iron, copper, zinc, molybdenum, silicone, etc). These minerals are required as chemical reagents or co-factors in metabolic reactions, therefore plants cannot survive without them. Nutrient dynamics involves processes such as wet and dry deposition, leaching, rock weathering, decomposition, mineralization and plant uptake. Ecosystems are generally open systems with both inputs and outputs, but in order to maintain stability, these must achieve a balance. Nutrient dynamics is a fundamental ecosystem process and as such, it can have broad-ranging effects on other processes such as primary productivity, forest health, and regeneration.

***Significance/Justification*: **Nutrient dynamics, involving recycling of elements from organic residues as well as inputs and outputs, is subject to impacts from a variety of sources. For example, elevated deposition of nitrogen was found by Berg and Matzner (1997) to accelerate the rate of decomposition of newly-fallen litter but it slowed the rate of decomposition of later-stage humus. Acid deposition may increase the rate of mineral leaching, especially for base cations. Changes in forest systems, either as a result of changing land use (Currie and Nadelhoffer 2002), from timber harvesting (Patric and Smith 1975; Swank and Waide 1980) or loss of a species due to introduced insects or diseases (Yorks et. al. 2004) can result in impacts to the nutrient balance. ERMN parks are exposed to many stressors, both from outside and from within. Maintaining healthy ecosystems involves the maintenance of healthy ecosystem processes and nutrient dynamics is one of the key processes that must be preserved.

***Proposed Metrics*: **Nutrient capitol is often partitioned into pools (living biomass, dead biomass, mineral soil, etc.) and quantified as weight per of mineral per unit bimass (mg/kg) or weight per area (kg/ha). When minerals are dissolved in water, they are usually expressed in units like mg/l or parts per million. For mineral export in streams, loss is expressed as a rate function such as kg/ha/year.

***Prospective Method(s) and Frequency of Measurement*: ** In order to establish current levels of mineral nutrients in ERMN park ecosystems, a comprehensive analysis of living and dead biomass will be required. This would involve mass spectral analysis of mineral matter, and chemical analysis of organic fractions; furthermore, these operations would have to be replicated in each ecosystem type at each park. It would also be desirable to monitor the key processes involved in nutrient dynamics (leaching, precipitation input, litter decomposition, stream export, mineralization, fixation, weathering etc.). Methods are available to monitor some of these processes (Mudrick et. al. 1994) but such undertakings would be very expensive. A more practical approach would be to monitor the inputs and outputs using the small watershed method

(Federer et.al. 1990). This method involves measuring inputs by analyzing minerals deposited in precipitation and dry atmospheric deposition and output from stream flow. For the latter, the volume of water flowing from the watershed is measured at a control point using a weir. The difference between nutrient input and output indicates whether or not the system is in relative balance. Furthermore, tracking these parameters over time permits the observer to see whether or not the ratios of inputs and outputs remain constant or are changing.

Limitations of Data and Monitoring**:** Developing a viable system for monitoring nutrient dynamics, even using the small watershed approach, may be too difficult and expensive to conduct system-wide, therefore perhaps one or a few watersheds could be instrumented in key parks. However, making the assumption that one or a few small watersheds can be representative of the larger whole is tentative at best, since even adjacent watersheds can produce dramatically different responses (Hicks 1992). Prediction models may be useful in estimating certain watershed parameters, for example, using readily-available precipitation data to estimate stream flows. But even here, some mechanism for calibrating and validating model projections is needed, usually involving the collection of field data.

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***Related Environmental Issues and Linked Vital Signs*:** Mineral nutrients are primary resources required for the physiological functioning of all organisms within an ecosystem. The dynamics of these substances can alter the long-term health and productivity of the ecosystem. Many of the vital signs are linked with mineral nutrients. These include atmospheric and climatic factors (VS2, VS4). The soil and geologic material is one of the media through which processes such as plant uptake, leaching and mineralization take place (VS12). Groundwater hydrology (VS15) plays a role in nutrient dynamics in that leached elements may be find their way to deep storage pools in ground water. Communities (VS20, VS58), through litter production and decomposition (VS26, VS60) have an important effect on nutrient dynamics. And in the final analysis, nutrient dynamics is one of the drivers of primary productivity (VS59).

***Overall Assessment*:** Nutrient dynamics describe the complex processes involving climatic, hydrologic and biotic processes. Since minerals are requires by all plants and animals in the ecosystem, the nutrient status has a profound effect on the health and productivity of the organisms. But monitoring nutrient dynamics at the ERMN park level will be difficult and expensive, necessitating the use of available data and modeling methods in lieu of field-based monitoring. Perhaps a reasonable compromise would include the addition of a limited number of small reference watersheds in key locations. Data collected from these watersheds could be used to calibrate modeling projections.

Level 1 ► Air and Climate
Level 2 ► Air Quality
Level 3 ► Wet and Dry Deposition (VS2 - tributary)

Brief Description: "Deposition" refers to the deposition of, and trends in, pollutants that are carried in ambient air and deposited on National Park Service lands in the Eastern Rivers and Mountains Network (ERMN). Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through wet deposition (rain or snow), occult deposition (cloud or fog), or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Although it is important to know total deposition, (i.e., the sum of wet, occult, and dry deposition) to park ecosystems, often only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. through the National Atmospheric Deposition Program (NADP). Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems. For the most part, atmospheric pollutants are primary predisposing and inciting factors affecting ecosystem health.

***Significance/Justification*:** All of the ERMN parks occur within or downwind of areas of the central and eastern United States that have a significant influence from industrialization and power generation. Vehicular burning of fossil fuels in the densely populated region also contributes much to the atmospheric pollution load. These pollutants have potentially sweeping effects on the entire ERMN (Lovett 1994). Deposition effects are manifested in a variety of ways, depending on the pollutant. Direct effects include foliar necrosis and dieback in plants. In other cases, pollutants may be directly toxic to plants, animals or microorganisms. However, indirect effects that result, for example, from soil acidification and its effect on mineral cycling may be more significant in the long term. Atmospheric pollutants potentially affect resources such as water and mineral nutrients. Aquatic ecosystems, particularly in headwater areas with low buffering capacity, can become episodically acidified, resulting in significant degradation of aquatic communities. The long-term effects, such as altered litter decomposition, micro-flora and fauna, altered nutrient cycling, and acidification of aquatic ecosystems pose major threats to the health, fecundity and sustainability of the terrestrial and aquatic ecosystems and lead to an overall loss of species diversity.

***Proposed Metrics*:** Due to the relative lack of regional data on dry and occult deposition, the ERMN will use wet deposition data reported as kilograms per hectare per year (kg/ha/yr).

***Prospective Method(s) and Frequency of Measurement*:** The ERMN will rely on wet deposition data measured at NADP sites in and near network parks. NADP measures a comprehensive suite of anions and cations; deposition rates of total wet sulfur (S) and total wet inorganic nitrogen (N) (ammonium plus nitrate ions) are included in the summaries.

***Limitations of Data and Monitoring*:** Ideally, the ERMN would evaluate total deposition, i.e., wet plus dry plus occult, to assess the threat to resources. Realistically, only wet deposition data are available. Wet deposition values will be based on interpolated data for most ERMN parks since only one park has an on-site NADP monitor. Because of meteorology and intervening terrain, interpolated deposition values may be somewhat different than those that would be based on on-site data. Wet deposition data should be compared to the results of water quality monitoring data to understand linkages between contributing areas and aquatic ecosystems. Atmospheric pollution is often a problem of regional, even global proportions, therefore it may be difficult or impossible to mitigate. Moreover, the sources of pollution are outside the parks and, therefore, cannot be controlled by the NPS.

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Related Environmental Issues and Linked Vital Signs**:** Atmospheric pollutants directly affect a number of ecosystem processes. In particular, soils can absorb and accumulate pollutants, altering nutrient cycling. Acidified soils have lower base saturation and therefore lower fertility resulting in reduced bio-productivity. Runoff, throughfall and direct input to streams and lakes can result in impacts to aquatic systems as well as to terrestrial systems which can lead to loss of sensitive species.

Overall Assessment**:** Atmospheric deposition of sulfur and nitrogen compounds is prevalent in the EMRN region and can affect numerous ecosystem processes, including nutrient cycling, litter dynamics and regeneration. Indirect effects of pollutants may be the enabling of invasive species and the loss of T&E species due to habitat alteration or direct toxicity. Amphibian species appear to be especially sensitive to water-borne pollutants. The ERMN can rely on the existing network of NADP monitors for wet deposition data, but because the NPS cannot control sources of pollution outside park boundaries, mitigation and reclamation of damaged ecosystems will be difficult.

Level 1 ► Air and Climate
Level 2 ►Weather and Climate
Level 3 ► Weather and Climate (VS4 - tributary)

Brief Description: Weather and climate have the potential to affect the distribution of all species. The present geographical distribution of species can be presumed to be a consequence of past redistributions as weather and climate have changed over time leading up to the present. However, species redistributions have been shown to occur at different rates as exemplified by different rates of latitudinal movement of tree species distributions following the last glacial maximum in North America (Davis 1987). This argues for regarding species movements during climate change individually, and predicting these movements based on the ecological tolerances of each species. In contrast, all species are constrained to some extent by the ecological relationships with other species. Species with commensal, predator-prey, or other "symbiotic" interrelationships are likely to have coordinated redistributions, and thus not follow individualistic patterns. Any models taking into account the effects of climate change must recognize this duality. Species at the northern or southern limits of distributions are the ones that could serve as indicators of response to climate change. A 1.5 – 4.5 degrees C warming by the end of the twenty-first century, as indicated by Overpeck et al. (1991), could lead to as shift of southern species to the north (Solomon and Kirilenko, 1997). Species isolated geographically to the highest altitudes, such as red spruce in the southern Appalachians, could be extirpated locally (Adams et al. 1985).

***Significance/Justification*:** Weather and climate are but one set of factors representing the multidimensional niche of species, and thus their current distributions. The geographical redistribution of species may have cascading effects on other dependent species. To the extent that some tributary watersheds occur at the highest altitudes, high altitude distributions are expected to be the most vulnerable. Likewise, organisms at the fringes of climatically restricted population distributions are the most vulnerable to additional stressors caused by human activities. Such species may serve as indicators of these interactions (De Groot et al.1995). As described elsewhere, Mahon (2004) provides lists of plants, vertebrates and communities of special concern in the New River Gorge, some of which may be among the first to respond to climate change.

***Proposed Metrics: Prospective Method(s) and Frequency of Measurement*:** Two groups of species deserve monitoring: those that have rather distinct north and south boundaries and those that are restricted to high altitudes. For the former, population abundances and other indices of population vitality can be measured at the boundaries of the species distributions. For the latter, a similar approach may be taken for altitude. As with any measurement, and especially climatically related indicators, interannual variation can be a critical component in interpreting the relevance of long-term data to species distribution. For example, weather extremes of precipitation, temperature, storminess, daytime vs. nighttime averages, etc. may each have influences on populations locally and over short time intervals.

***Limitations of Data and Monitoring*:** Most species of interest will be ones distributed outside of boundaries of NPS control. Consequently, any monitoring program must be driven by the distribution of the chosen indicator species rather than only the distribution in lands under federal jurisdiction of the NPS.

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***Related Environmental Issues and Linked Vital Signs*:** Weather and climate directly affect a number of other ecosystem attributes, especially related to sensitive and T&E species, biodiversity, etc. Because climate does not act in a vacuum, other vital signs such as levels of atmospheric pollution (VS1, VS2, VS3) may interact with climate to affect organisms. Indirect effects may occur such as the enabling of invasive species and loss of focal species or communities.

***Overall Assessment*:** Climate plays a fundamental role in terrestrial ecosystems, and particularly tributary watersheds at high altitudes. Therefore climatic changes, and associated alterations in weather patterns, have the potential to change the distribution of species and associated communities. Current models of climate change are notoriously general and geographically imprecise. In some ways, changes in species distribution may more effectively indicate climate change than the use of climate change projections to predict future distributions of species. Regardless, a great deal of uncertainty will accompany either approach, and it is the accumulation of multiple trends of many indicators that will ultimately be the most compelling evidence for change.

Level 1 ► Geology and Soils
Level 2 ►Geomorphology
Level 3 ► Stream/River Channel Characteristics (VS07-tributary)

Brief Description: "Stream channel characteristics" (SCC) refers to the physical component of stream habitat and includes information on stream size, sinuosity, bed roughness, channel slope, bank condition, water depths, water velocities, substratum, and the amount and type of organic matter and instream vegetation. Usually, measurements of physical habitat are collected in conjunction with hydrology (flow), water chemistry, and riparian vegetation sampling. Individual SCC variables are typically summarized using traditional statistical measures of magnitude and variance such as means and standard deviations, as well as with more complex, integrated, measures such as habitat complexity and substrate stability.

Significance/Justification**:** Measures of habitat quality are essential components of any long-term stream monitoring program. Along with water quality, the physical characteristics of stream channels are the main proximate determinants of biotic integrity in streams. Individual species or life stages of a single species vary with respect to physical habitat requirements and preferences, and SCC variables summarized at various spatial scales represent a multidimensional representation of individual habitat patches important to component species. Over long stream reaches, it is the diversity and stability of available habitat patches as determined by SCC, as well as the spatial and temporal relationships among them, that shape biological communities in streams (Townsend 1989, Poole 2002). Moreover, SCC indirectly affect biological communities through their influence on energy flow. Specifically, SCC variables such as bed roughness, pool-riffle ratios, and the amount of coarse woody debris within the channel are primary determinants of carbon and nutrient flow through, and retention within, lotic systems (Brookshire and Dwire 2003).

In undisturbed watersheds, SCC are determined by interactions between climate, basin size, geology, and terrain (Gordon et al. 1992). However, both natural and human induced disturbances can have profound effects on SCC and consequently biological integrity. For example, increases in the amount of impervious surfaces associated with urbanization within a watershed have been shown to cause higher storm flows which leads to bank erosion (i.e., changes in stream size), increased sedimentation (reduced substrate size and increased substrate embeddedness, especially in riffle areas), shallower and less complex pool habitats, and ultimately reduced biotic integrity (Richards et al. 1996, Snyder et al. 2003). Consequently, understanding status and trends in biological integrity of stream ecosystems requires basic information on SCC.

Proposed Metrics**:** Important SCC metrics include mean channel width, substratum size distributions (especially in riffles), substrate embeddedness, amount and size distribution of large woody debris, proportion of stream channel area with submerged and emergent vegetation, pool-riffle ratios, number and size of dispersal barriers (beaver dams, waterfalls, man-made dams and dikes), measures of bank stability, and variation in depth and flow patterns. In addition, integrated measures such as instream habitat diversity, fish cover, and substrate stability are also recommended.

***Prospective Method(s) and Frequency of Measurement*:** Two types of methods are typically used to assess stream habitat: quantitative assessments that involve detailed measurements of stream channel and bank characteristics (e.g., Rosen 1994); and visual-based rapid assessments that involve relative rankings of important stream habitat features. Quantitative assessments have the advantage of providing accurate and unbiased data that can be collected by trained field technicians. However, these measurements are time consuming and require a significant amount of field equipment. In contrast, with visual-based rapid approaches, a very large amount of information can be acquired in a relatively small amount of time with little equipment. However, these visual rankings are more sensitive to investigator bias and consequently a significant amount of training and testing is required to minimize subjectivity and ensure comparability. It is usually recommended that a single biologist conducts all visual based assessments.

If possible, a combination of the two approaches should be used with quantitative methods applied less frequently (perhaps once every five years) and rapid assessments used more often (e.g., annually). The EPA has developed and tested a visual-based habitat assessment approach which is described in Barbour et al. (1999). Specific rapid protocols have been developed for both low and high gradient stream systems. Quantitative habitat assessment protocols are described by Meador et al. (1993), Rosgen (1994), and Kaufmann and Robinson (1997).

***Limitations of Data and Monitoring*:** As previously mentioned, substantial training of field crews is required to minimize subjectivity of the qualitative rankings used in the rapid habitat assessment approach. Moreover, rankings are often affected by current weather conditions. In contrast, the quantitative approach is more expensive and time consuming and requires a significant amount of equipment. However, the

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***Related Environmental Issues and Linked Vital Signs*:** SCC are primary determinants of stream biotic assemblages and consequently should be considered along with any stream faunal groups selected for monitoring (VS39, VS41, VS42, VS43, VS44, and VS47). In turn, SCC are themselves effected by weather (VS4), geology (VS11) and riparian (VS28) and upland (VS57) land cover characteristics.

***Overall Assessment*:** SCC should be considered a high priority vital sign because they are both drivers of ecological integrity in streams, and sensitive to many of the sources of environmental degradation noted for ERMN.

Level 1 ► Water
Level 2 ►Hydrology
Level 3 ► Surface Water Hydrology – Streams, Rivers, Wetlands (VS13,14)

Brief Description**:** Tributary watersheds consist of a complex of streams, riparian zones, and wetlands that are supported by various combinations of precipitation, surface water, and groundwater. The physiographic origins, flow patterns, hydrodynamics, and water quality attributes determine the mosaic of aquatic habitats in these systems. Understanding hydrologic reference conditions is critical for diagnosing hydrologic stressors.

Significance/Justification**:** Understanding and measuring the hydrology of tributary watersheds is central to many other ecological aspects of assessing the condition of these systems (Forman 1995, Thorp et al. In press). As the primary driver of these systems (Mitsch and Gosselink 2000), and as a link between climate and weather indicators, hydrology should be considered a core vital sign. From an energy perspective, the ecological integrity of stream communities in mid-reach streams is determined mostly by factors that affect retention, transport, and the quality of organic matter from headwater areas upstream, and by factors that influence instream primary production within mid-reach areas. The effects of non-point source pollutants associated with agriculture and urban land use in upstream or adjacent landscapes (both of which are significant concerns in ERMN) have been shown to affect energy pathways in these reaches. Herbicides and increased sediment inputs have been shown to reduce overall instream primary production with subsequent changes in macroinvertebrate diversity and production (Guasch et al. 1998). Acidification of stream habitats has also been shown to alter primary production in streams.

Proposed Metrics: Hydrologic measurements are relatively standardized. The placement of equipment to acquire those data, however, must be strategically considered. Each park unit should determine its needs for hydrologic data, potential partnering opportunities, and costs in order to design an appropriate hydrologic monitoring system. Given the importance of hydrology to these systems, it is important to capture as much of these data as possible. In some case, particularly for floodplains and wetlands, observed hydrologic indicators can be used as surrogates to quantitative measures.

Prospective Method(s) and Frequency of Measurement**:** Hydrologic data for streams typically originates from gaging stations, from which flow rates, frequency of flooding, and other hydrologic measurements can be derived. Gaging stations, however, can only be installed on limited reaches due to relatively high expense of the equipment. Modeling and other types of simulations can be used to extend empirical measurements across other streams. The network of gaging stations can be extended through partnering efforts with other agencies and organizations. Groundwater measurements for streams and wetlands typically are taken from wells and piezometers placed at various depths into soil and geologic strata. Automated or hand measurements can be taken. The sampling regime for hydrologic measurements should be coordinated with water quality data collection to allow the computation of loadings and to increase efficiency.

***Limitations of Data and Monitoring*:** Due to the expense of installing and maintaining an extensive hydrologic monitoring system, careful consideration should be given the locations of sampling stations and types of surface water and groundwater data.

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***Related Environmental Issues and Linked Vital Signs*:** Hydrologic measurements are key to diagnosing stressors in tributary watersheds. Whether obtained as quantitative measurements or as qualitative observations, documenting deviations from reference hydrologic conditions is important.

***Overall Assessment*:** Hydrologic data are neither easy nor inexpensive to obtain, but their utility to monitoring the condition of aquatic ecosystems is critical.

Level 1 ► Water

Level 2 ►Water Quality

Level 3 ► Water Chemistry - Core Parameters (VS16 - tributary)

***Brief Description*:** Water quality in its broadest interpretation refers to all of the factors that influence the hydrology, biogeochemistry, and habitats of aquatic organisms. In a more typical interpretation, water quality of surface water relates to physical and chemical factors such as temperature, pH, conductivity, nutrient content, sediment load, and toxicant presence. For ground water, sediment load could be eliminated as a factor. Sources of degraded water quality can originate from point sources and non-point sources. Point sources are represented primarily by wastewater treatment systems from municipal and industrial sources. Non-point sources are more diffuse, and are influence by land uses. With advances and implementation of wastewater treatment over the past three decades, many point sources have been reduced greatly, although problems have not been eliminated totally. Degraded water quality from non-point sources continues to be a chronic and difficult problem to resolve. Land use normally is the major factor affecting water quality. Rowcrop agriculture and various urban land uses have strong effects of water quality in addition to direct discharges from point sources (Lowrance et al. 1984). Headwater streams are strongly influenced nonpoint sources because they are the first to receive surface water it passes from land-based activities to low order streams (Brinson 1993). Unless in-stream processes improve water quality, nutrients and other contaminants will be transferred to higher order streams downstream (Bayley 1995, Jones and Mulholland 2000). Natural variation in water hardness, acidity, and dissolved oxygen are major controls over species composition of aquatic communities. These controls, however, may be easily overwhelmed by eutrophication, excessive sediments, and toxicants that stress aquatic organisms and eliminate whole suites of species. In tributary watersheds, water chemistry is more reflective of the geologic and topographic characteristics of the landscape than for larger rivers. The complex geology of the Appalachians can create circumstances where relatively short stream reaches and individual tributaries can have different water chemistry than their neighbors (USEPA 2000, Snyder et al. In review.) Such variability produces extraordinary biodiversity.

Significance/Justification: Eutrophication from excess nutrients (e.g., nitrogen and phosphorus) can be a significant stressor in tributary watersheds. Over time, eutrophication typically alters energy pathways by increasing primary production, which often results in lower dissolved oxygen concentrations resulting from oxygen demand from accumulated organic matter. These changes usually lead to highly productive, but taxonomically and trophically simple biological communities in both streams and wetlands (Sandin and Johnson 2000). Herbicides also disrupt energy pathways, but they cause reductions in instream primary production, and pesticides directly affect survival and reproduction of populations of invertebrates and fish. Excess turbidity caused by high levels of suspended sediment decreases oxygen levels and photosynthesis rates, impairs the respiration and feeding of aquatic organisms, destroys fish habitat, and kills benthic organisms (Johnston 1993). In wetlands, high sedimentation rates decrease the germination of many wetland plant species by eliminating light penetration to seeds, lowering plant productivity by creating stressful conditions, and slowing decomposition rates by burying plant material (Jurik et al. 1994, Vargo et al. 1998, Wardrop and Brooks 1998).

Proposed Metrics**:** Protocols for monitoring the status and changes in water quality are well established and have been used for decades. As a practical matter, the purpose and scope of monitoring should depend on the issues being addressed. For example, if water quality problems are suspected to be the result of acid mine drainage, and remediation practices are implemented, intensive sampling of acidity, heavy metals, and sensitive biota may be the indicators of choice. On the other hand, if the question revolves around protecting habitat quality, and no specific problems are apparent or known, sampling for periphyton, benthic macroinvertebrates, and fish at infrequent intervals may be the method of choice. There are a number of established principles for designing monitoring programs to detect effects of human activities (Downes et al. 2002).

Prospective Method(s) and Frequency of Measurement**:** As for the proposed metrics, the method and frequency of measurements should match the purpose of the sampling program. Methods range from characterizing benthic, diatom, or fish communities (IBIs) (Karr 1999, Karr and Chu 1999) to analysis for specific chemical components. Problem areas may be identified with a number of spatially explicit analytical tools, such as EPA-developed Analytical Tools Interface for Landscape Assessments (ATtILA).

Limitations of Data and Monitoring**:** Many streams have been sampled for water quality through state and federal programs. However, headwater tributaries are among the least sampled on a routine basis, simply because they are so abundant and occur everywhere in the landscape. In remote areas, sampling is difficult because of access problems, and few historical data exist as points of reference. The chemical and sediment components of streams may vary widely depending on stream discharge. Stream discharge varies seasonally and with differences in base flow vs. storm flow. Time of day in which data are recorded can have an influence on the concentration of dissolved oxygen. For these and other reasons, the intent of a water quality sampling program should be carefully evaluated before a commitment is made to dedicate resources to the time and expense necessary for program implementation. Priority for remedial action can be assigned to sites that have been identified as being impaired, such stream segments that are on 305(b) and 303(d) lists and where other assessments have identified problems. Sites should be identified that are slated to have application for National Pollution Discharge Elimination System (NPDES) permits, changes in landuse/landcover, construction of roads, and additional housing and other development activities. Sampling programs to detect factors associated with climate change require special attention to planning and review (Grimm 1993, Halpin 1997).

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***Related Environmental Issues and Linked Vital Signs*:** Water quality potentially responds to changes in land cover/land use (VS 57, VS 58), in atmospheric and climatic patterns (VS1-VS4), geology and soils (VS6- VS12), and hydrologic features (VS14, VS15). Because human activities often are involved in the introduction of invasive species, and human habitation is relevant. Visitor usage (VS54) can locally affect aquatic ecosystem through changes in productivity and nutrient dynamics (VS59, VS61). In short, nearly all activities that occur in watersheds have the potential to alter the pattern that exists on the landscape is a reflection of the sum of the abiotic, biotic and anthropogenic factors that interact over it.

***Overall Assessment*:** Given all of the related environmental links and issues listed above, water quality in its various dimensions should become a critical component of any vital signs program. ERMN parks are themselves part of a larger landscape, are affected by actions that take place beyond their boundaries, and aquatic ecosystems can be one of the pathways that provide a conduit for transporting problems through park boundaries. The relatively long history of and experience in water quality monitoring can provide a suite of effective tools to enable managers to anticipate changes and take remedial actions, when necessary.

Level 1 ► Water
Level 2 ► Water Quality
Level 3 ► Water Chemistry - Expanded Parameters (VS17)

***Brief Description*:** Measurement of water quality parameters beyond the Core Parameters.

Significance/Justification: Many different inorganic and organic chemicals and compounds are capable of entering river systems and causing problems for aquatic biota. There are also physical and biological parameters which can cause problems in the riverine ecosystem. This sampling will serve to monitor such potential stressors to such ecosystems.

***Proposed Metrics*:** Cations (Ca, Mg, Na, K), anions (PO_4, NO_2, Br, SO_4, Cl, acid neutralizing capacity), turbidity, suspended sediments, BOD, COD, alkalinity, N & P compounds, chlorophyll a, VOC's, SVOC, pesticides, PCB's, trace metals, etc. Other organic and inorganic substances, enteric viruses, fecal coliform bacteria (total coliform enterococci, fecal *Streptococci* groups, *E. coli*), *Giardia*, etc.

***Prospective Method(s) and Frequency of Measurement*:** Standardized methods have been developed for measurement of these parameters in freshwater (APHA et al. 1992). Frequency of measurement may be determined at a later date, depending on park management objectives (Rosenberg and Resh 1993).

***Limitations of Data and Monitoring*:** There are always intervals between sampling when fluctuations in parameter values may exist which may not be recorded. Values can change quickly, and some diurnal fluctuations can be expected. Both natural anomalies and anthropogenic activities can cause these fluctuations, and are not often predictable (Boyd 1979).

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***Related Environmental Issues and Linked Vital Signs*:** Very closely linked to surface water hydrology (VS13), Weather and climate (VS4), Air chemistry (VS2), Groundwater hydrology (VS15) and water quality-core parameters (VS16).

***Overall Assessment*:** Fluctuation possibilities are possible depending on weather and climate and surface water hydrology. Temperature readings may be available without cost. Frequency of data collection will depend heavily upon overall management objectives.

Level 1 ► Biological Integrity
Level 2 ►Invasive Species
Level 3 ► Invasive Plants, Animals, Diseases – Status and Trends (VS18 – emphasis on aquatic species)

Brief Description**:** "Invasive plants, animals, diseases – status and trends" is a very broad subject, including 1) invasive plants and animals whose primary effect is displacement of native species and 2) species of exotic insects, animals or pathogens that attack and cause injury or death to native species. Examples include purple loosestrife, zebra mussels, and exotic crayfish. An abundance of invasive plants and animals is often associated with disturbed or degraded ecosystems (Dachler and Carino 2000); therefore their presence serves as an **indicator** of ecosystem health. On the other hand, invasive species, including insect and disease pests, can dramatically alter an ecosystem (serving as an **inciting factor** for ecosystem decline), thus directly affecting processes such as **succession, nutrient cycling, and food webs**. Furthermore, the altered ecosystem state may result in a system that is **unhealthy,** has lower **diversity** and having reduced **fecundity** of native species. Invasive species, including insects and diseases, have resulted in dramatic historic changes to numerous ecosystems in North America, including the ERMN area. The recent invasion of the hemlock wooly adelgid is an interesting example of a terrestrial pest that could significantly impact tributary watersheds (e.g., McClure and Cheah 1999).

Significance/Justification**:** Native plants and animals, that make up a particular ecosystem have co-evolved over millions of years, therefore native ecosystems have developed a state of dynamic equilibrium. The introduction of non-native species into a system can upset this balance. Because of the globalization of human activities, including travel, shipping and deliberate species introduction for food and agricultural purposes, many species have been moved from their native ranges and have been introduced to exotic environments around the world. In most cases, these species have been unsuccessful or have blended into the local environment with minor impacts. But for some species, their introduction has led to their becoming "invasive". This term refers to the condition that exists when a non-native plant or animal becomes highly aggressive in its new environment and causes habitat destruction, replacement of native species or results in damaging outbreaks (e.g., Davis et al. 2000). National parks are especially vulnerable to species invasion because of the large number of visitors who enter the parks and serve as potential vectors of invasive organisms. Invasive organisms can bring about alterations in **species composition, bio-productivity, and nutrient cycling**, changing the **diversity, vigor and fecundity** of the ecosystem. The direct effects of an invasion include species displacement, infestation, and mortality of host species, but indirect effects such as shifts in species composition, altered nutrient cycling, modified temperature and light regimes, and increased demand for oxygen. The introduction of organisms has resulted in greater and more lasting ecosystem damage than virtually anything brought about by humans in recent history (Pimentel et. al 2000, With 2002).

Proposed Metrics**:** In situations where an invading organism has not yet fully colonized a suitable habitat, the metric chosen to describe the colonization is usually the rate of advancement of the infestation or killing front. In areas where infestation or invasion has already occurred, the numbers of invading organisms per unit area or the proportion of the suitable habitat that has been colonized can be a valuable metric. Finally, the presence and impact of an invasive organism or disease is often measured by the number or proportion of hosts that are colonized or killed. This can be more difficult in aquatic ecosystems than in terrestrial ones.

***Prospective Method(s) and Frequency of Measurement*:** Surveys of invasive plants and animals in aquatic ecosystems are conducted by federal and state agencies. For newly-introduced organisms that are potentially damaging, records and surveys are conducted by the USDA, Animal and Plant Health Inspection Service. Before any in-house programs are undertaken by the ERMN, this information should be investigated to determine whether or not it meets the needs of the NPS. Furthermore, hazard rating systems that have been developed, especially in the case of insects and diseases, primarily for terrestrial ecosystems, but they may be useful in determining whether or not a particular park is likely to have a problem with an invading organism. Once it is determined that a need exists for additional on-site surveys for an invading organism, the appropriate sampling scheme should be developed and tailored to the specific situation. With a problem as broad and diverse as invasive plants – animals, insects and diseases, surveys will need to be developed that are capable of detecting damaging populations and that fulfill the needs of the ERMN.

Limitations of Data and Monitoring: Perhaps the greatest limitation of monitoring for invasive organisms is the sheer magnitude of the task. The ERMN parks occupy extensive areas of land and are situated in areas with extensive and remote components. Organisms can quickly spread from non-system lands onto parks. Invasive organisms can persist below detection levels and rapidly explode into outbreaks when favorable conditions occur. Data collected only on NPS lands will be of limited value in predicting the ambient population levels and therefore, may not be useful in preventing spread of organisms from adjacent ownerships. It incumbent upon the NPS to choose carefully which organisms to focus on, concentrating on those most likely to do significant damage to the parks and to utilize data collected by other agencies, whenever possible.

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Related Environmental Issues and Linked Vital Signs**:** Species invasion could be linked with Air and Climate, such that an altered climatic regime may predispose a site to being invaded. Many invasive aquatic species are spread either in the water column or by translocation from waterbody to waterbody by vectors such as birds or boats. Invasive species may displace plants and/or animals from unique natural communities, and this is especially true for T&E species, which may be living close to the limits of their existence in the absence of aggressive competitors.

Overall Assessment**:** Invasive plants, animals, diseases – status and trends is a very broad topic, and includes both exotic invasive species that displace natural species or communities as well as insects and diseases that injure or kill native species. These agents are, however, some of the most damaging of those affecting both terrestrial and aquatic ecosystems. Their spread is directly related to human activities, either deliberate, accidental or unintentional. This makes them all the more significant in National Parks where human visitation rate is high. There may be opportunities to share monitoring costs with partners, but for certain key species, the NPS may wish to develop their own on-site survey data. The decisions regarding which species and how to sample for them should be weighed carefully, since valid surveys may be difficult, expensive and time consuming.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Riparian Plant Communities (VS28 - tributary)

***Brief Description*:** Riparian plant communities are particularly vulnerable to invasive species because their linear nature exposes them to large areas containing potential invaders (Simberloff et al. 2005). The range of conditions of riparian zones varies widely in tributary watersheds because site conditions range from those with saturated soils to soils that are well drained and infrequently flooded. Given this range of conditions, there is little selective pressure against any particular group of species with narrow habitat preferences. Species that are dispersed by wind or water can most easily invade, and roads and trails provide additional corridors for effective dispersal. Further, disturbance factors, such as the development of point bars on rivers, opening of forest canopies by storms, and alteration of floodplains by beaver activity tend to expose sites to colonization of invasives. Once established, invasive species may compete for light, water, and nutrient resources, all of which are generally abundant in riparian areas.

***Significance/Justification*:** Most plant species classified as invasive tend to concentrate along forest edges other areas of disturbance (Woods 1997, Walker and Smith 1997). There are few tree and shrub species, such as *Ailanthus altissima* (tree-of-heaven) and *Eleagnus angustifolia* (Russian olive), that may form monospecific stands (Miller 2004). Once established, it is difficult for native trees to compete with them. Several shrubs and vines can form dense growths in disturbed areas and forest edges, including *Ligustrum sinense* (Chinese and other privets) , *Lonicera* spp. (Japanese and other honeysuckles), *Celastrus orbiculatus* (oriental bittersweet), and *Pueraria montana* (kudzu). *Microstegium virmineum* (Japanese stiltgrass) is a grass can become particularly abundant in along stream banks and in floodplains. It is shade tolerant and a prolific seeder, and thus easily disperses. Based on its capacity to out-compete other ground covers, especially in shade, the species has the capacity to suppress other herbaceous species. *Polygonum cuspidatum* (Japanese knotweed) is becoming in increasingly prevalent. *Lythrum salicaria* (purple loosestrife) and *Phragmites communis* are obligate wetland plants found in some riparian settings (Galatowitch et al. 1999). Global warming may expand the ranges of many southern invasives into riparian areas of the ERMN. Since the rate of expansion of plant species is not predictable from ecological traits (Clark et al. 1998), empirical data are needed to follow trends in real time.

***Proposed Metrics*:** Classification and inventory are the first steps in the assessment of any natural resource. If an agreed-upon list of potentially problematic species can be developed, and vulnerable sites for invasion within and surrounding each of the NPS lands are identified, this information can provide the basis for an inventory to track the occurrence and spread of invasive species. Baseline data generally are not available.

***Prospective Method(s) and Frequency of Measurement*:** Annual surveys of the vulnerable sites in and around the ERMN sites would provide information on trends and conditions for riparian invasive plants. Since many invasive species tend to disperse along highways and trails, sampling sites could be located where these conduits cross stream channels. Abundance measures should be developed to characterize the areal distribution and patchiness. A recent protocol has been developed to standardize the assessment of non-native invasive species (Morse et al. 2004).

Limitations of Data and Monitoring**:** To track changes over time, monitoring sites need to be established to illustrate where invasive species are absent as well as where they are present. Little training would be needed to recognize invasives because there are few of them, most are easily identified, and many are already familiar to most naturalists.

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Related Environmental Issues and Linked Vital Signs**:** Climate change could expand the range northward of a number of exotic species that are presently confined to warmer climates (VS 4). Because disturbance plays a large role in invasion, VS57 should be applicable.

Overall Assessment**:** There are few examples of invasive species causing the extirpation of other plant species, except on a small, site-specific basis. Often, invasives such kudzu seem prevalent because they occupy disturbed areas along forest edges where they are conspicuous. Areas with full canopy cover are unlikely to support most invasives, with *Microstegium virmineum* an exception because of its shade tolerance. It is recommended that a modest inventory program be set up so that the spread of exotic species along riparian corridors is noted. It could be coordinated with a program to follow the phenology of plants.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Riparian Birds (VS29 - tributary)

Brief Description: Riparian birds have a demonstrated utility as integrative indicators of the condition of tributary watersheds, including stream, wetlands and riparian habitats. A variety of bird species use riparian areas as habitat, and several species and selected guilds have been shown to respond to degradation of these ecosystems (Croonquist and Brooks 1993, Brooks et al. 1998). Louisiana waterthrush (*Seirius motacilla*, LOWA), one of the few obligate avian species in tributary watersheds of the ERMN, could serve as an ideal vital sign because of their dependence on interior forest as breeding habitat and use of clean, headwater streams for foraging (Prosser and Brooks 1998, O'Connell et al. 2003). Other songbird species are considered facultative in their use of tributary habitats, but their collective use, as measured as through community composition (e.g., Index of Biological Integrity) can provide confirming information about the condition of the landscapes surrounding tributary watersheds.

***Significance/Justification*:** Birds are well known to the public, and therefore, can garner significant public support and interest if used to express the condition of park units. Connectivity among aquatic habitats has been shown to affect faunal communities, including birds (Croonquist and Brooks 1993, Gibbs 1993). For example, movements of vulnerable species can be hindered by discontinuities among requisite habitats, which in turn can affect reproductive success and genetic diversity. Riparian songbirds are likely to respond primarily to changes in habitat structure and fragmentation, and less so to declining water quality. Waterbirds (i.e., waterfowl, shorebirds, and wading birds) are, in general, more common in larger waterbodies, such as emergent wetlands, lakes, and the floodplains and shores of large rivers. Thus, their utility as a vital sign for tiributary watersheds is limited.

***Proposed Metrics*:** For non-obligate avian species, an Appalachian Bird Community Index (BCI) has been developed for the ecoregions relevant for the ERMN and for its geographic extent (O'Connell et al. 2000, O'Connell et al. (report). Scores for the overall BCI and for individual metrics can be used to assess condition of both terrestrial and tributary habitats. Density of LOWA breeding pairs may have utility (O'Connell et al. 2003). If census data are not available, habitat suitability index (HSI) models are available for several key species (e.g., Prosser and Brooks 1998), and can be easily implemented by field personnel.

***Prospective Method(s) and Frequency of Measurement*:** Protocols for censusing songbirds are standardized, which increases the likelihood of acquiring high quality data. For songbirds, presence / absence data and relative abundance can be collected during the breeding season using auditory and visual identification by trained observers. As few as 1-3 observations per site are sufficient to gather useful data. Equipment needs are minimal, and personnel costs are reasonable.

***Limitations of Data and Monitoring*:** There are two primary limitations to using riparian birds as vital signs; relatively narrow sampling window corresponding to accepted dates during the breeding season (approximately 8 weeks for the ERMN region) and the requirement of using observers trained in auditory and visual identifications of birds. Although the latter is essential for collecting quality data, trained birders are readily available.

***Key References*:**

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Croonquist, M. J., and R. P. Brooks. 1993. Effects of habitat disturbance on bird communities in riparian corridors. J. Soil Water Conserv. 48(1):65-70.

Gibbs, J. P. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.

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Prosser, D. J., and R. P. Brooks. 1998. A verified habitat suitability index for the Louisiana Waterthrush. J. Field Ornith. 69(2):288-298.

***Related Environmental Issues and Linked Vital Signs*:** Riparian birds can provide linkages to terrestrial ecosystems which greatly affect the condition of tributary watersheds. Brooks et al. (1998) proposed an integrative approach to assessing condition of these systems using LOWA and riparian bird communities as two of several potential metrics.

***Overall Assessment*:** Use of riparian songbirds is recommended as a suitable indicator for tributary watersheds with utility for terrestrial ecosystems as well.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Riparian Mammals (VS30)

Brief Description: Aquatic mammals, such as mink (*Mustela vison*) and river otter (*Lontra canadensis*), are sensitive to bioaccumulation of contaminants found in aquatic habitats. Their availability through legal fur-trapping activities or road kills may provide a source of tissues for analyses of these contaminants. In addition, park units where trapping is not permitted may provide refugia for these two riparian predators, and thus, warrant monitoring. Beaver (*Castor canadensis*) activities frequently alter the entire structure and function of headwater streams and wetlands, and thus, their populations need to be monitored so that these effects on other species, habitats, and park facilities can be assessed.

Significance/Justification: Mink and river are carnivores at the top of food webs, thus, they are sensitive to accumulation of contaminants (e.g., heavy metals, PCBs) that enter aquatic ecosystems. If such contaminants are suspected or possible, and sources of tissue samples are readily available (e.g., legal fur trapping, road kills), then a modest monitoring program may justified. Also, river otter can be an attractant for visitors and recreationists, so for some units, periodic presence / absence and/or density surveys may be warranted. In selected units, species of conservation concern, such as water shrews (*Sorex palustris*) or river otters, may warrant the use of targeted protocols for actual capture or photo-capture to confirm their existence. The presence of beaver can significantly alter aquatic and vegetation features of tributary watersheds, with resultant habitat and/or economic damage. Thus, monitoring their presence and the extent of areas affected may be warranted.

Proposed Metrics**:** For bioaccumulation studies, the concentration of suspected contaminants in target tissues (e.g., fat, reproductive organs) can be measured by qualified laboratories. Density measures derived from observed sign or captures of individuals would suffice for the other purposes.

Prospective Method(s) and Frequency of Measurement**:** Standard methods are available for most of the suggested approaches to monitoring riparian mammals. The expected frequency of measurement is likely to be seasonal or annual. For detection of populations, inexpensive field monitoring protocols have been developed for river otters and beaver for the Delaware Water Gap unit (Swimley et al. , Serfass). Standard trapping protocols are available for detecting shrews and other small mammals.

Limitations of Data and Monitoring**:** The primary limitation to using riparian mammals as a vital sign is the low density of the carnivores (i.e., mink, river otter, shrew), which can translate to limited data availability. Beaver, however, can be common and are readily observable.

Key References**:**
Serfass and Brooks
Serfass

Swimley

Related Environmental Issues and Linked Vital Signs**:** Riparian mammal species, although few in number, can be important as sentinels (mink, river otter) and agents (beaver) of environmental change.

Overall Assessment**:** Use of riparian mammals as a vital sign is recommended in selected situations. Their use may be appropriate where park units serve as refugia for aquatic furbearers that are legally harvested outside parks, and where bioaccumulating contaminants are suspected to be present.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Aquatic macroinvertebrates (VS39 - tributary)

Brief Description**:** "Aquatic macroinvertebrates" refers to aquatic and semi-aquatic invertebrates that inhabit the stream bottom (i.e., benthic) and can be observed without the aid of a microscope. Most biological monitoring programs that use aquatic macroinvertebrates derive a suite of metrics from field samples that are based on the taxonomic and trophic structure and composition of the entire assemblage to infer ecological condition.

Significance/Justification**:** Aquatic macroinvertebrates are a vital component of all healthy stream ecosystems. They are instrumental in nutrient and carbon dynamics and are themselves an important link in stream food webs (Webster 1983). Moreover, unlike fish and periphyton (i.e., benthic algae), aquatic macroinvertebrate assemblages are both productive and diverse in virtually all undisturbed streams with permanent flow (Lenat et al. 1980). This is an important consideration in ERMN because many of the smaller tributary streams of component parks have steep gradients and numerous natural barriers that impede the movement of fish, as well as dense canopies that restrict light and consequently limit algal productivity. As a result, fish and periphyton assemblages are often represented by very few species even in undisturbed streams. Other advantages of using benthic macroinvertebrate assemblages to monitor streams include: 1) they are good indicators of local conditions because most benthic species are either sessile or have limited migration patterns through their aquatic phases; 2) they exhibit wide variation in tolerance among species and life stages to environmental stresses; 3) many species have long life cycles relative to other groups which allows inference regarding temporal trends; and 4) sampling aquatic macroinvertebrate assemblages is relatively easy and inexpensive, and has minimal effects on resident biota (Rosenberg and Resh, 1993, Barbour et al. 1999; and references therein). In addition, because aquatic macroinvertebrates have been by far the most commonly used group for biological monitoring of aquatic habitats in North America, a large suite of aquatic macroinvertebrate summary metrics have been evaluated with respect to natural variation and responses to numerous sources of degradation (Rosenberg and Resh 1993).

Proposed Metrics**:** Numerous individual assemblage response metrics can be easily calculated from macroinvertebrate sample data. However, the accuracy of measures (i.e., ability to detect impact when one occurs or the failure to detect impact when one does not occur) varies considerably among metrics and within metrics among different types of stressors. Numerous evaluations regarding the accuracy and responsiveness of many of the commonly used aquatic macroinvertebrate metrics have been done, and thorough discussions of these efforts can be found in Jackson and Resh (1993) and Barbour et al. (1999). Metrics found to be consistently robust in terms of detecting impact include several taxonomic richness measures such as total taxa richness, number of taxa of the orders Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT richness), various community similarity indices such as Margalef's Index and Simpson's Index, and some functional metrics such as the proportion of shredders (Jackson and Resh 1993). However, calculation of a much larger suite of metrics is advisable for several reasons. First, the time and expense required to calculate dozens of metrics is small relative to the time it takes to collect samples. Second, the post-hoc evaluations of the accuracy of aquatic macroinvertebrate metrics described above were designed to assess the usefulness of metrics over wide regions including different types of streams exposed to many different stressors and using information collected by different investigators using different collection methods. It is likely that within a smaller region involving a smaller set of stream types (such as ERMN) and more standardized methods and personnel, that other metrics will be revealed to be robust indicators of change. A broader list of potential macroinvertebrate metrics can be found in Resh and Jackson (1993), Kerans and Karr (1994), and Barbour et al. (1999). Various integrated measures that combine scores generated for multiple metrics into a single score have also been developed for various types of streams and geographic regions (e.g., Kerans and Karr 1994, DeShon 1995).

***Prospective Method(s) and Frequency of Measurement*:** The US Environmental Protection Agency has developed rapid bioassessment protocols for sampling stream macroinvertebrates and analysis of macroinvertebrate data (Plafkin et al. 1989, Barbour et al. 1999) that should be useful in ERMN. These protocols advocates one of two stratified sampling approaches based instream habitat (Barbour et al. 1999). The “single habitat” protocol calls for sampling in riffle areas only because aquatic invertebrate assemblages tend to be most productive and diverse in these habitats, and because traditional sampling devices (e.g., D-frame kick nets, Hess samplers, etc.) are most effective in shallow, flowing water. However, riffle habitats are often not prevalent or easily discernable in the steep, cascading streams common in ERMN. In contrast, the “multiple habitat” approach involves sampling several different habitat types including cobble-bottoom areas, snags, macrophytes, and vegetated banks (Barbour et al. 1999). However, this approach requires estimates of the relative areas occupied by each habitat which either requires extensive measurements or a qualitative ranking that introduces a source of investigator bias. A more randomized approach such as that used by Snyder et al. (2002) in Delaware Water Gap National Recreation Area streams may be a modification worth considering because it provides repeatable and comparable data irrespective of stream type.

The other major question regarding sampling methods is whether to use field-based identification or laboratory based identification of specimens. The field based ID methods require considerably less time and expense, and sufficient taxonomic resolution of specimens is possible with field based methods as long a biologist with sufficient experience with the regional fauna is part of the field team. Lab methods provide greater flexibility because samples can be identified to various levels of taxonomic resolution and samples remain available for further analysis. However, increased handling and sample processing time associated with laboratory identifications increases the expense of the program dramatically.

***Limitations of Data and Monitoring*:** Timing of aquatic macroinvertebrate sampling is critical for obtaining comparable data, especially if sampling is conducted only once per year. Component macroinvertebrate species have complex and highly variable life cycles often including terrestrial stages. Consequently, macroinvertebrate assemblage metrics exhibit considerable natural variation across seasons. As a result, sampling windows tend to be relatively small and there is little flexibility in sampling schedules which can make scheduling field crews and other logistical matters difficult to accommodate. In addition, considerable investigator experience is required to identify organisms to levels beyond the ordinal stage in the field. As a result, protocols that require field identifications usually require a biologist with considerable taxonomic experience with the regional fauna. Moreover, for generic or species level identifications, samples usually need to be returned to the laboratory for processing which is time consuming and expensive. Finally, macroinvertebrate distributions within stream reaches are highly contagious and thus a large number of samples or complex stratification schemes are necessary to effectively characterize the assemblage.

***Key References*:**

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***Related Environmental Issues and Linked Vital Signs*:** Aquatic macroinvertebrates are sensitive to a wide range of instream, riparian, and landscape features that vary naturally and are themselves altered by human disturbance. In particular, stream channel characteristics (VS07), water quality (VS17 and VS17), stream hydrology (VS13), riparian vegetation (VS28), periphyton (VS42), landscape pattern (VS58) and land use change (VS57) are all linked to aquatic macroinvertebrate assemblage measures.

***Overall Assessment*:** Based on the proven ability of measures of aquatic macroinvertebrate assemblage structure and composition to discern impact and change, combined with the relatively high degree of power to assess change and the relatively low cost to sample, aquatic macroinvertebrates are probably the single best biological group to monitor to assess the health of small and mid-sized streams.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Periphyton – Algae, diatoms, fungi, bacteria and protozoa (VS40)

Brief Description: "Periphyton" refers to benthic algae, or algae that attach to substrate. For the most part, bioassessment programs incorporating periphyton use assemblage level metrics or indicator species to infer ecological condition. To a lesser extent, periphyton biomass (e.g., chlorophyll *a* concentrations) and productivity measures have been used.

***Significance/Justification*:** Benthic algae are the main primary producers in streams and therefore represent an important component of many stream food webs. In addition, periphyton assemblages often help stabilize substrata and provide habitat for many other organisms including bacteria, protozoans, and macroinvertebrates. Attributes that make periphyton good candidates for incorporation into the Vital Signs monitoring program include: 1) rapid reproduction and short life cycles making them valuable indicators of short-term impacts, 2) as primary producers, algae are most directly affected by physical and chemical changes in the environment, 3) algal assemblages have been shown to be sensitive to some stressors when other groups (e.g., macroinvertebrates and fish) were not, and 4) sampling for algae is relatively easy and inexpensive (Patrick 1973, Barbour et al. 1999). In addition, depending on the region, many algal species, especially diatoms, have been identified to have specific tolerances to various types of pollution strengthening the likelihood of establishing causal linkages between assemblage composition and specific stressors (Lowe 1974).

***Proposed Metrics*:** Many of the same indices (e.g., Shannon Diversity, Percent Community Similarity) and assemblage metrics (e.g., species richness) commonly used for other groups have also been used for periphyton assemblages to infer ecological condition. In addition, indices specific to periphyton have been developed such as the Pollution Tolerance Index (Lange-Bertalot 1979). Barbour et al. (1999) describes a suite of metrics that have been shown to be useful in inferring ecological condition and includes metrics such as species richness, percent sensitive diatoms, percent aberrant diatoms (diatoms with morphological anomalies), percent mobile diatoms, and the proportional representation of several key indicator species. In addition, estimates of periphyton biomass have also been used to in bioassessments, especially surveys designed to detect effects of nutrient enrichment or toxicity (Stevenson and Lowe 1986).

***Prospective Method(s) and Frequency of Measurement*:** There has been relatively little standardization in terms of periphyton sampling for bioassessment. However, Barbour et al. (1999) describe two rapid bioassessment protocols for periphyton that are a composite of techniques used in bioassessment programs in the States of Kentucky, Oklahoma, and Montana. The main difference between the two approaches is that one uses laboratory based identification and the other is a completely field-based protocol. Either approach would be useful although the completely field-based approach may be only sensitive to fairly large environmental changes.

***Limitations of Data and Monitoring*:** Although periphyton is found in virtually all streams, smaller headwater streams in forested landscapes are typically too shaded through much of the year to support many species, although those that do occur tend to be adapted to low light conditions. Thus, either bioassessments involving periphyton should be limited to mid-reach streams (stream orders 3-5) where significantly more light penetrates forest canopies and reaches stream bottoms, or, sampling needs to be confined to a very narrow sampling window in early spring just prior to canopy development when periphyton populations tend to reach maxima (Barbour et al. 1999). Moreover, as with aquatic macroinvertebrates, species composition of periphyton assemblages exhibit considerable seasonal variation, mainly in response seasonal changes in light and temperature patterns. As a result, either repeated sampling is required among seasons, or sampling must be conducted over a fairly narrow time windows to ensure comparability. In addition, periphyton tends to be patchily distributed within a stream reach, even within apparently uniform stream sections. Consequently, although sampling is relatively easy, a significant number of samples are required to ensure the assemblage is accurately represented, and taxonomic expertise is required in the field. It may be useful to consider an adaptive sampling approach (e.g., Smith et al. 2003) for this group. Finally, periphyton is extremely sensitive to scouring and consequently samples need to be collected during prolonged periods of stable flow. Frequently the best periods to sample periphyton in terms of community composition (i.e., early spring) are also the least predictable in terms of stream flow.

***Key References*:**

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

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Stenvenson, R.J. and R.L. Lowe. 1986. Sampling and interpretation of algal patterns for water quality assessments. Pages 118-149 *in* Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems (B.G. Isom, editor).

***Related Environmental Issues and Linked Vital Signs*:** Periphyton assemblages are sensitive to a wide range of instream, riparian, and landscape features that vary naturally and are themselves altered by human disturbance. In particular, stream channel characteristics (VS07), water quality (VS17 and VS17), stream hydrology (VS13), riparian vegetation (VS28), landscape pattern (VS58) and land use change (VS57) are all linked to periphyton measures. In turn, periphyton assemblage composition and productivity can potentially affect the composition and productivity of higher trophic groups including macroinvertebrates (VS41) and fish (VS44).

***Overall Assessment*:** Assessments using periphyton could add significantly to the vital signs monitoring program and they potentially offer diagnostic elements not obtained by aquatic macroinvertebrates or fish. However, there would also be considerable overlap in terms of information obtained with aquatic macroinvertebrates. Consequently periphyton might be considered a secondary group to monitor if sufficient resources are available.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Fish Communities - Streams (VS44)

Brief Description: "Fish Communities-Streams" refers to measures of the structure and composition of the fish assemblages in tributary streams.

***Significance/Justification*:** Fish are important components of most healthy stream ecosystems, occupying the top of the food web. Moreover, unlike other groups, the condition of fish populations is frequently of interest to the broad public due to their importance in terms of recreation and food. Even more importantly fish have numerous characteristics that are advantageous from a biological monitoring and assessment perspective which include: 1) they are relatively easy to collect and identify, 2) because they are among the longest lived species in streams and mobile, they are good indicators of long-term effects and broad habitat conditions, 3) the life histories and environmental requirements of most species are well known, and 4) they occupy positions throughout the aquatic food web and thus provide an integrateive view of watershed conditions (Karr 1986, Barbour et al. 1999). In addition, unlike aquatic macroinvertebrates and periphyton assemblages that exhibit wide natural variation seasonally, the relative abundance of fish species (excluding young-of-the-year individuals) remains relatively stable. As a result, fish sampling can occur over much broader sampling windows which allows more flexibility in terms of logistics.

***Proposed Metrics*:** Two approaches to drawing inferences regarding ecological condition of streams are proposed. The first is a multivariate analysis approach that compares community composition within a stream reach from one time to the next based on the relative abundance of component taxa. This method uses traditional multivariate ordination or classification techniques such as Principal Components Analysis, Canonical Correlation Analysis, Discriminant Analysis, or K-means clustering (see Gauch 1982 for detailed synthesis of multivariate methods), and is useful because it allows evaluations of overall structure (groupings of species) as well as changes in individual species. The second approach is the multi-metric approach that has become increasingly common for bioassessments involving fish, especially in North America. This approach involves the calculation of numerous individual assemblage metrics, combining the information into a single score (i.e., index of biotic integrity or IBI), and comparison of the combined index score with the range of scores expected for streams of similar type in the region (Karr et al. 1986). Both integrated scores and values for individual metrics can be evaluated and monitored and have been shown to be useful assessment tools.

The metrics selected for inclusion into multi-metric approach depend on stream type and geographic region because expected scores for individual metrics vary in ecologically healthy streams. However, metrics usually include measures of species richness and composition, trophic composition, and fish abundance and condition (Karr 1987). Moreover, indices of biotic integrity (IBIs) have been developed for most regions of the country and many stream types (e.g., cold water streams versus warm water streams, highland streams versus coastal or piedmont streams, high-gradient versus low gradient, etc.) (see Miller et al. 1988 for review). Particularly relevant to ERMN are IBIs developed and tested for highland streams in Maryland

(Roth et al. 1998), the mid-Atlantic highlands (McCormick et al. 2001), and for small, cool water streams in the Appalachian Plateau of West Virginia (Leonard and Orth 1986).

***Prospective Method(s) and Frequency of Measurement*:** Because most species reproduce only once a year, populations tend to be stable throughout the year (if young-of-the-year fish are not considered). As a result, a single sampling during the relatively long period of base flow conditions is all that is required to adequately assess fish assemblages within a stream reach. Electrofishing has been shown to be the most effective sampling technique for collecting information on the broad fish community. Depending on stream size and depth profiles, a DC current backpack electroshocking unit, or a towable Pram electroshocking unit, operated by a team of either two or three individuals experienced with electoshocking techniques is needed to effectively sample small and mid-sized wadeable streams. The team should include a fish biologist with knowledge of the regional fauna so that species-level identifications can be made in the field. Alternatively, samples would need to be returned to the lab which not only is significantly more costly and time consuming but also can impact the resident fauna. Detailed methods for fish shocking protocols are described in Barbour et al. (1999).

***Limitations of Data and Monitoring*:** Because of natural barriers to movement like waterfalls and beaver dams, fish assemblages are naturally species poor in many smaller streams. For example, many of the streams draining steep terrains in Delaware Water Gap National Recreation Area support only a single species of fish (Ross et al. 2003) making assemblage level assessments meaningless. Thus, ecological assessments using fish should probably be limited to mid-reach streams. In addition, fish tend to be poor indicators of intermittent stresses because they will move from stream reaches during stressful times but return when conditions improve. Finally, relative to other groups, fish sampling requires more expensive and labor-intensive methods to effectively survey.

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Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

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***Related Environmental Issues and Linked Vital Signs*:** Fish assemblages are influenced by a wide range of instream, riparian, and landscape features that vary naturally and are themselves altered by human disturbance. In particular, stream channel characteristics (VS07), water quality (VS17 and VS17), stream hydrology (VS13), riparian vegetation (VS28), periphyton (VS42), landscape pattern (VS58) and land use change (VS57) are all linked to fish assemblage measures.

***Overall Assessment*:** Fish assemblage measures can be an excellent indicator of ecological condition in streams if the resident fauna is well known and reference conditions have been documented. Fish sampling is more expensive than for other groups such as periphyton and macroinvertebrates, but it is easier to effectively characterize fish assemblages. Moreover, because they are longer lived, fish assemblage metrics provide a better indicator of long-term trends in ecological condition than other groups.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Vernal Pond Amphibians (VS46)

Brief Description: "Vernal Pond Amphibians" (VPA) refers to frogs (anurans) and salamanders (caudates) that breed in vernal ponds. Although in the truest sense, the term "vernal pond" refers exclusively to wetlands that fill with water in spring, the term is often more generally applied to all seasonal or semi-permanent wetlands that do not contain fish (Colburn 2004), and we adopt that broader definition here. In fact, in the eastern United States, many, if not most, temporary or seasonally-flooded wetlands actually fill in autumn soon after leaf off when deciduous trees cease transpiration, although they usually reach their maximum size and volume in spring.

***Significance/Justification*:** Concern over the status of amphibians has heightened in recent years due to increasing evidence of global and regional population declines, range reductions and extinctions (Wyman 1990). Although degradation of local habitat is implicated in many of the noted declines, they are not limited to highly degraded areas. Significant losses have been reported even in relatively pristine areas such as National Parks (Blaustein and Wake 1990), indicating the potential role of regional (e.g., acid deposition) and global (e.g., ozone depletion and climate change) stressors. In addition, because they require relatively undegraded aquatic and terrestrial habitats to complete their life cycles, as well as intact migration corridors between the two habitats, vernal pond amphibians are widely viewed as indicators of the condition of the larger forested ecosystem.

***Proposed Metrics*:** Assemblage level measures such as species richness would be difficult and expensive to incorporate into long-term monitoring because accurate and precise measures would require repeated visits to each selected pond over a relatively long sampling interval, and require the use of a variety of sampling methods (visual encounter surveys, call counts, cover boards, etc.) that require significant expertise or training and are difficult to standardize when using multiple field crews (Heyer et al. 1994).

We propose using the number of wood frog (*Rana sylvatica*) and spotted salamander (*Ambystoma maculatum*) egg masses within selected ponds as vital sign metrics. Both species are ubiquitous, their eggs are relatively easy to identify and count, egg mass abundances of both species have been shown to strongly correlate with the number of breeding adults (_ and Patton), and they both occur in vernal ponds at approximately the same time and so sampling could be conducted concurrently. At the same time, the two species differ in many important life history traits such as mobility, longevity, and mating behaviors that make them vulnerable to different stressors.

***Prospective Method(s) and Frequency of Measurement*:** Complete censuses of the number of egg masses of both species laid in individual vernal pools are often possible and relatively rapid for smaller pools that contain low or moderate egg mass densities. However, sampling is advisable for larger wetlands and for wetlands with very high egg mass densities. Transect sampling (e.g., Snyder et al. 2005) should be used in larger ponds and high density ponds.

Limitations of Data and Monitoring**:** Egg mass abundance data for both species are highly sensitive to annual variation in weather during and for some period proceeding breeding seasons (Semlitsch 2000), and consequently relatively long periods are required to assess trends. In addition, the timing of sampling will vary annually depending on when ponds thaw making scheduling the timing of field sampling more difficult. Finally, egg mass abundance of both species is highly dependant on hydroperiod. Thus, to the extent possible, hydroperiod should be considered a priori in the site selection process.

Key References**:**

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Related Environmental Issues and Linked Vital Signs**:** Wood frog and spotted salamander egg mass abundances are affected by several key environmental variables that vary naturally at different scales. In particular, temperature and rainfall patterns (VS4), wetland hydrology (VS14), groundwater hydrology (VS15), wetland plants (VS23), and landscape pattern (VS58) are all important determinants of breeding pond selection and use by these two species. Some of these variables such as wetland hydrology and landscape pattern (e.g., relative pond isolation) can be accounted for *a priori* in the sampling design and site selection process. The other variables will need to be accounted for *post hoc* in the trend analysis phase.

Overall Assessment**:** Measures of pond breeding amphibians can be sensitive indicators of overall ecosystem health. The sensitivity of this group of animals to local threats such as direct habitat destruction and disruption of migration corridors through roads and other changes in land use, combined with noted sensitivity to regional and global stressors make vernal pond amphibians a high priority group to monitor.

Level 1 ► Biological Integrity
Level 2 ► Focal Species or Communities
Level 3 ► Streamside Salamanders (VS47)

***Brief Description*:** Streamside salamanders have been identified as a strong candidate as a vital sign for tributary watersheds in the ERMN. An index using the streamside salamander community has been developed for the Mid-Atlantic Highlands. The index responds to multiple stressors and can be implemented by personnel with minimal training.

***Significance/Justification*:** Most amphibian species require both terrestrial and aquatic habitats at various times of their life cycles, although some species spend considerably more time in truly aquatic habitats. Streamside salamanders occupy the functional role of aquatic vertebrates in the upper reaches of tributary watersheds, where fishes are often absent. Although the community of plethodontid salamander species is modest in size, the presence / absence of selected species correspond with patterns of landscape disturbance. An index has been developed and tested throughout the Mid-Atlantic Highlands; Streamside Plethodontid Assessment R (SPAR, Rocco et al. 2004), corresponding to the ERMN.

***Proposed Metrics*:** The SPAR index has been calibrated for different regions of the Mid-Appalachian Highlands, and thus, is readily available for use. Also, initial results of bioaccumulation studies, have shown that concentrations of contaminants can be measured in streamside salamanders by qualified laboratories (G. Rocco, pers. comm.), adding another potential use of this taxon as a vital sign in the ERMN. Density and abundance measures derived from captures may also serve as vital signs, although additional calibration is necessary.

***Prospective Method(s) and Frequency of Measurement*:** Standard sampling protocols have been developed (SPAR, Rocco et al. 2004). These protocols have been tested and found to be appropriate for use with trained volunteers. The sampling period is fairly broad (spring through autumn). Relatively few plots (usually 3-5, 2 m x 2 m) are sampled per 1 km reach of stream to generate data for the SPAR index. An automated computation process has been developed to simplify data analysis (G. Rocco, pers. comm.). Sampling can be conducted in conjunction with aquatic macroinvertebrate sampling.

***Limitations of Data and Monitoring*:** Some training is required to conduct SPAR sampling, but this does not limit the utility of the technique.

***Key References*:**
Rocco, G. L., R. P. Brooks, and J. T. Hite. 2004. Stream plethodontid assemblage response (SPAR) index: development, application, and verification in the MAHA. Final Report. U.S. Environmental Protection Agency, STAR Grants Program, Washington, DC. Rep. No. 2004-01. Penn State Cooperative Wetlands Center, University Park, PA. 33pp+figs& app.

Related Environmental Issues and Linked Vital Signs**:** Streamside salamanders appear to be responsive to multiple stressors in tributary watersheds. These amphibian taxa provide another dimension to understanding the response of biological communities to stressors in these systems, much like aquatic macroinvertebrates and fish.

Overall Assessment**:** An established index using streamside salamanders has been developed and tested. The SPAR index is suitable for use as a vital sign.

Level 1 ► Biological Integrity
Level 2 ► At-risk Biota
Level 3 ► Park-specific Threatened, Endangered or Focal Species/Communities (VS49, VS50)

Brief Description: As public resource agencies, parks have an obligation to address conservation issues related to **state and federal threatened and endangered species, and species of special concern**, such as those that are vulnerable to various stressors (e.g., Noss 1990). In addition, there are selected species from a variety of taxa that may serve as broadly-defined **indicator species** (e.g., McKenzie et al. 1992). For example, carnivores like river otter or habitat-altering species such as beaver may serve as keystone species that influence the ecological integrity of biological communities.

***Significance/Justification*:** Species such as mink, river otter and northern pike are carnivores at the top of food webs, thus, they are sensitive to accumulation of contaminants (e.g., heavy metals, PCBs) that enter aquatic ecosystems. If such contaminants are suspected or possible, and sources of tissue samples are readily available (e.g., fur trapping, road kills, recreational fishing), then a modest monitoring program may justified. Also, river otter can be an attractant for visitors and recreationists, so for some units, periodic presence / absence and/or density surveys may be warranted. In selected units, species of conservation concern, such as water shrews, rare fishes, dragonflies, spotted and bog turtles, or uncommon orchids may warrant the use of targeted protocols to confirm their existence. The presence of beaver can significantly alter aquatic and vegetation features of tributary watersheds, with resultant habitat and/or economic damage. Thus, monitoring their presence and the extent of areas affected may be warranted.

***Proposed Metrics*:** For bioaccumulation studies, the concentration of suspected contaminants in target tissues (e.g., fat, reproductive organs) can be measured by qualified laboratories. Density measures derived from sampling protocols, observed sign or captures of individuals may suffice for the other purposes.

***Prospective Method(s) and Frequency of Measurement*:** Standard methods are available for most of the suggested approaches to monitoring aquatic flora and fauna, especially for state and federal threatened and endangered species (e.g., Barbour et al. 1999). Recovery plans for such species, if available, should be consulted to obtain appropriate sampling techniques and to learn about regional goals for recovery. The expected frequency of measurement is likely to be seasonal or annual for most species. Inexpensive field monitoring protocols have been developed for river otters and beaver for the Delaware Water Gap unit (Swimley et al. 1998, Serfass and Brooks 1998).

***Limitations of Data and Monitoring*:** The primary limitation to using rare species and indicator species as vital signs is the low density of many species which can translate to limited data availability. Some indicator species, however, can be common and are readily observable.

***Key References*:**

Barbour, M.T., J. Gerritsen, B.D. Synder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish, Second Edition. U.S. Environmental Protection Agency, Office of Water, EPA/841-B-99-002, Washington, DC.

McKenzie, D. H., D. E. Hyatt, and V. J. McDonald (eds.). 1992. Ecological indicators. Proc. Int. Symp. Ecological Indicators, 16-19 October 1990, Fort Lauderdale, FL. Elsevier Science Publishers, Ltd., Esses, England. Vols. 1 & 2.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conserv. Biol. 4(4):355-364.

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***Related Environmental Issues and Linked Vital Signs*:** **Rare** aquatic species, although few in number, can be important as sentinels (mink, river otter) and agents (beaver) of environmental change. Rare flora may be sought after by collectors, so collection permits and take issues may arise and need to be monitored.

Overall Assessment: Use of rare species and indicators species as vital signs is recommended in selected situations. Their use may be appropriate where park units serve as refugia for aquatic species that are legally harvested inside or outside parks, and where bioaccumulating contaminants are suspected to be present. Specific park units may need to collaborate regionally with other public and private conservation organizations to ensure the survival of species of concern.

Level 1 ► Human Use
Level 2 ► Point-Source Human Effects
Level 3 ► Bioaccumulation (VS52)

***Brief Description*:** Monitor bioaccumulation of contaminants to assess toxicity levels in riverine predators. Significant as indicator of cumulative toxicity within aquatic organisms, early warning for terrestrial predators such as bald eagles, and monitoring for human consumptive use restrictions.

***Significance/Justification*:** Fishes at or near the top of the food chain have long been recognized as predisposed to bioaccumulation of toxins in the environment (Hickey et al. 1966). These fishes are very often targeted by recreational fishermen, as they include trout, bass, and other popular species. Such fishes tend to concentrate airborne toxins such as mercury (Josephson 1976; Kurland et al. 1960). Benthic freshwater macroinvertebrates are most commonly used to monitor metals and organic contaminants such as PCB's (Rosenberg and Resh 1993). Bioaccumulation is used when ambient concentrations are too low for direct analysis (Graney et al. 1983). Given recreational activities in NPS lands include fishing, it is important to know of any related risk to public health.

***Proposed Metrics*:** Bioconcentrations in parts per million (ppm) and parts per billion (ppb).

***Prospective Method(s) and Frequency of Measurement*:** Fish samples will be collected twice yearly using gill nets and/or beach seines. Benthic freshwater macroinvertebrate samples will be collected with kick nets. Tissue samples will be analyzed using gas chromatography and atomic absorption spectrophotometry.

***Limitations of Data and Monitoring*:** Migratory fishes captured may reflect concentrations from other locations. Requires standardized methods.

***Key References*:**

Graney, R.L., Jr. , D.S. Cherry, and J. Cairns, Jr. 1983. Heavy metal indicator potential of the Asiatic clam (*Corbicula fluminea*) in artificial stream systems. Hydrobiol. 102: 81-88.

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Kurland, L.T, et al. 1960. Minimata disease. World Neurology 1: 370-395.

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Related Environmental Issues and Linked Vital Signs**:** Bioaccumulation is the endpoint of pollutants that are acquired by groundwater hydrology (VS15), surface water hydrology (VS13), and air chemistry (VS2).

Overall Assessment**:** Bioaccumulation of toxins data will give managers the ability to make recommendations regarding personal consumption of fish from their jurisdictional waters.

Level 1 ► Ecosystem Pattern and Process
Level 2 ► Land Cover/Land Use
Level 3 ► Landscape Change and Pattern (VS57, 58, tributary)

Brief Description: "Landscape Pattern" refers to the states and distribution of the various dominant cover types, as they exist within a landscape mosaic. In addition to the current pattern, historic patterns (Braun 1950) should be considered, as well as trends and changes in landscape patterns. These changes can be useful **indicators** of the natural and human-caused forces acting upon the landscape (Alig and Butler 2004). Turner et al. (2003) examined the landscape-level changes in the Appalachian region (including much of the ERMN) and found that during the four-decade interval from 1950 to 1990, the amount of forest cover increased and fragmentation decreased, but they cautioned that recent housing development in the region may offset many of these gains. Human impacts are a critical element in the changing landscapes of the ERMN and Ritters et al. (2000) indicate that land cover information provides a mechanism to place humans into ecological assessments.

***Significance/Justification*:** Human activities are primary drivers in landscape-level changes in the Appalachians (Ritters et. al. 2000). Given that 70 – 80 percent of the landscape falls into the tributary watershed category, most activities affect this watershed component (Brooks et al. this document). Historical occurrences such as agricultural clearing, agricultural abandonment, timbering, surface mining, forest fire control, predator eradication, hunting regulation, insect and disease introductions and urban sprawl are all examples of how humans have contributed to landscape-level changes over the last hundred and fifty years. ERMN parks are in-effect islands within an ever-changing mosaic of land, and changes outside the ERMN parks can potentially affect the ecological properties within the parks (Brosofske et. al. 1999). Changes are particularly relevant to tributary watersheds where human activities outside of NPS land can affect downstream ecosystems located within NPS land. Roads have a particularly significant fragmenting effect on terrestrial ecosystems (Forman 2000; Trombulak and Fressell 2004). Changes in landscape pattern can alter habitat for neotropical birds, mammals (Dijak and Thompson 2000) and forest wetlands (Gibbs 2000). Because land use patterns surrounding the ERMN are changing and these changes have the potential for altering the ecological characteristics within the parks, it is important that park managers be aware of this process and how it is likely to affect them.

***Proposed Metrics*:** Landscape ecology is a field that uses spatial analysis methods to evaluate the pattern of various land cover types at different spatial scales. Metrics include the proportion of a given landscape occurring in a particular cover type and indices of patchiness, fragmentation, connectivity etc. In addition, changes in linear features such as streams and riparian zones, while not occupying large surface areas, have a profound effect on aquatic resources. These metrics can be used to compare among landscapes or to observe temporal changes in a single landscape.

Prospective Method(s) and Frequency of Measurement: Spatial analysis methods begin with imagery (aerial photography, satellite images, etc.) and databases (USGS topographic information, ownership, etc.). Image information requires interpretation in order to determine what the visual information represents. Interpretation can be facilitated by image enhancing methods, such as digital color transformations. The resulting information is used to create a geographic information system (GIS) that incorporates multiple layers of spatial information, such as land use, ownership, cover type, topography, etc. Software packages are available that provide powerful tools for organizing, interpreting and displaying the information. Spatial statistics can be used to analyze the data (Gardner et. al. 1987), and models constructed using information from known landscapes can be used to predict the states of other landscapes (Trombulak and Frissell 2004).

Limitations of Data and Monitoring**:** A substantial amount of landscape-level information currently exists, much of which is public record, and therefore inexpensive to acquire. The problem with many available sources of images or spatial data is that they must be adapted to the specific use required (e.g. ERMN parks). The detail, scale and type of imagery may not suit the specific purpose of the ERMN, requiring that new and expensive data need to be gathered. The development of a system-wide GIS can be a daunting task, requiring that either contractors or trained NPS employees complete the work. Furthermore, as Li and Wu (2004) warn, landscape analysis often falls short of meeting its high expectations due to conceptual flaws in pattern analysis, inherent limitations of landscape indices and improper use of pattern indices.

Key References**:**
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Brosofske, K.D., Chen, J., Crow, T.R., & Saunders, S.C. 1999. Vegetation responses to landscape structure at multiple scales across a northern Wisconsin, USA pine barrens landscape. Plant ecology, 143: 203-218.

Dijak, W.D. & Thompson, F.R. 2000. Landscape and edge effects on the distribution of mammalian predators in Missouri. Journal of Wildlife Management, 64(1): 209-216.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology, 14(1): 31-35.

Gardner, R.H., Milne, B.T., Turner, M.G., & O'Neill, R.V. 1987. Neutral models for the analysis of broad-scale landscape pattern. Landscape Ecology, 1(1): 19-28.

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Ritters, K.H., Wickham, J.D., Vogelman, J.E., & Jones, K.B. 2000. National land-cover data. Ecology, 81: 604

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Turner, M.G., Pearson, S.M., Bolstad, P. & Wear, D.N. 2003. Effects of land-cover change on spatial pattern of forest communities in the Southern Appalachian Mountains (USA). Landscape Ecology, 18: 449-464.

***Related Environmental Issues and Linked Vital Signs*:** Landscape pattern is related to many environmental issues, particularly ones having to do with anthropogenic effects, such as pollution, land use, settlement, etc. Landscape patterns are linked with almost all the vital signs identified for ERMN parks. Atmospheric and climatic patterns (VS1- VS4) vary across the landscape, and these factors, in turn, create patterns in vegetation and land use. Geology and soils (VS6- VS12) also contribute to landscape patterns, as well as do hydrologic features (VS14, VS15). Because human activities often are involved in the introduction of invasive species, and human habitation is part of the landscape pattern, the pattern of introduction of invasive species (VS18) often the follows patterns of human activity (transportation, settlement, etc.). Plant and animal communities (VS 20- VS48) are specifically adapted to their environment, which changes across the landscape. Visitor usage (VS54) can locally alter an ecosystem, therefore imposing an anthropogenic pattern on the landscape. Finally, bio-productivity and nutrient dynamics (VS59, VS61) are specifically linked to the landscape pattern. In short, the pattern that exists on the landscape is a reflection of the sum of the abiotic, biotic and anthropogenic factors that interact over it.

***Overall Assessment*:** Landscape pattern is a result of the interaction of numerous factors (historic and present). ERMN parks are themselves part of a larger landscape, and are affected by actions that take place beyond their boundaries. The discipline of landscape ecology has been developing in recent years and involves using imagery, data, technology and statistical tools to analyze and interpret spatial information. ERMN managers can use these methods to assess current conditions in their parks as they relate to the larger landscape. Use of this tool may enable managers to anticipate changes and take remedial actions, when necessary.